RESOLUTION AS A FUNCTION OF THE BAND-WIDTH IN A TELEVISION SYSTEM

A THESIS

Presented to

the Faculty of the Division of Graduate Studies

Georgia Institute of Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Electrical Engineering

by

Morris David Prince

March 1949

MW 7-6-49

106151

RESOLUTION AS A FUNCTION OF THE

BAND-WIDTH IN A TELEVISION SYSTEM

Approved:

Date Approved by Chairman March 16, 1949

ACKNOWLEDGMENTS

On the completion of this work I wish to express my sincerest thanks to Professor M. A. Honnell for his patient guidance and constant encouragement in the prosecution of this thesis. I should also like to thank Mr. J. E. Garrett and the staff of the Georgia Tech Engineering Experiment Station Photo Lab for their assistance with the photographic problems encountered in this research.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE PAGE

RESOLUTION AS A FUNCTION OF THE BAND-WIDTH IN A TELEVISION SYSTEM

INTRODUCTION

The ability of the television system to reproduce subject matter viewed by the camera determines the quality of the television image. Among the many factors which affect this quality are resolution, flicker, contrast, color, line structure, picture size, viewing distance, speed of moving objects, viewing history of the observer, room conditions, intensity of object illumination, and the viewing angle. The resolution, or the amount of detail the system can reproduce, is one of the most important and controversial of these considerations. It will be the principal purpose of this thesis to investigate the effect of the band-width upon this resolution.

Resolution has been investigated many times analytically[1,2,3,4,5]

---

[1] A. V. Bedford and G. L. Fredendall, "Analysis, Synthesis, and Evaluation of the Transient Response of Television Apparatus," Proc. I.R.E., Vol. 30, October, 1942, pp. 112-146.

[2] R. D. Kell, A. V. Bedford, and G. L. Fredendall, "A Determination of Optimum Number of Lines in a Television System," RCA Review, Vol. 5, July, 1940.

[3] H. A. Wheeler and A. V. Loughren, "The Fine Structure of Television Images," Proc. I.R.E., Vol. 26, May, 1938, p. 540.

[4] P. Mertz and F. Gray, "A Theory of Scanning and Its Relationship to the Characteristics of the Transmitted Signal in Telephotography and Television," Bell System Technical Journal, Vol. 13, September, 1934, p. 464.

[5] J. C. Wilson, "Channel Width and Resolving Power in Television Systems," Journal of the Television Society (London), Series 2, Vol. 2, June, 1938, pp. 397-419.

and experimentally,[6,7,8,9] but the results are neither explicit nor complete due to the complexity of the problem. The subject is one of great importance since the relationship between the resolution and the band-width must be known in order to design a system to reproduce a given amount of detail. Also, the selection of the optimum number of lines in a television system depends upon this information. The approach used here is an experimental one with many of the conclusions presented in the form of photographs of television images.

---

[6] M. W. Baldwin, Jr., "The Subjective Sharpness of Simulated Television Images," Proc. I.R.E., Vol. 28, October, 1940, pp. 458-468.

[7] A. V. Bedford, "Figure of Merit for Television Performance," RCA Review, Vol. 3, July, 1938, p. 36.

[8] E. W. Engstrom, "A Study of Television Image Characteristics," Proc. I.R.E., Vol. 21, December, 1933, pp. 1631-1651.

[9] O. H. Schade, "Electro-Optical Characteristics of Television Systems," Part IV, RCA Review, Vol. 9, December, 1948, p. 653.

DESCRIPTION OF EQUIPMENT

Television Equipment

The television system employed consisted of a camera connected to a monitor by a coaxial cable. No intermediate-frequency or radio-frequency sections were used. The equipment layout is shown in Figures 1 and 2. The nominal system standards are given in the following table:

Table I

Nominal System Standards

Scanning method	non-interlaced
Line number	350 lines/field
Line frequency	14,000 lines/sec.
Field frequency	40 fields/sec.
Approximate video band-width	2 1/2 mc.
Aspect ratio	4:3
D-C Reinsertion	none

The television camera, U.S. Army Type CFN-59 AAE, was designed for guided-missile operation. Description of similar equipment is found in the literature.[1,2] The power supply was adapted to 117-volt a-c operation with the exception of the camera filament circuit, which was

---

[1] M. A. Trainer and W. J. Poch, "Television Equipment for Aircraft," RCA Review, Vol. 7, December, 1946, p. 469.

[2] C. J. Marshall and L. Katz, "Television Equipment for Guided Missiles," Proc. I.R.E., Vol. 34, June, 1946, p. 375.

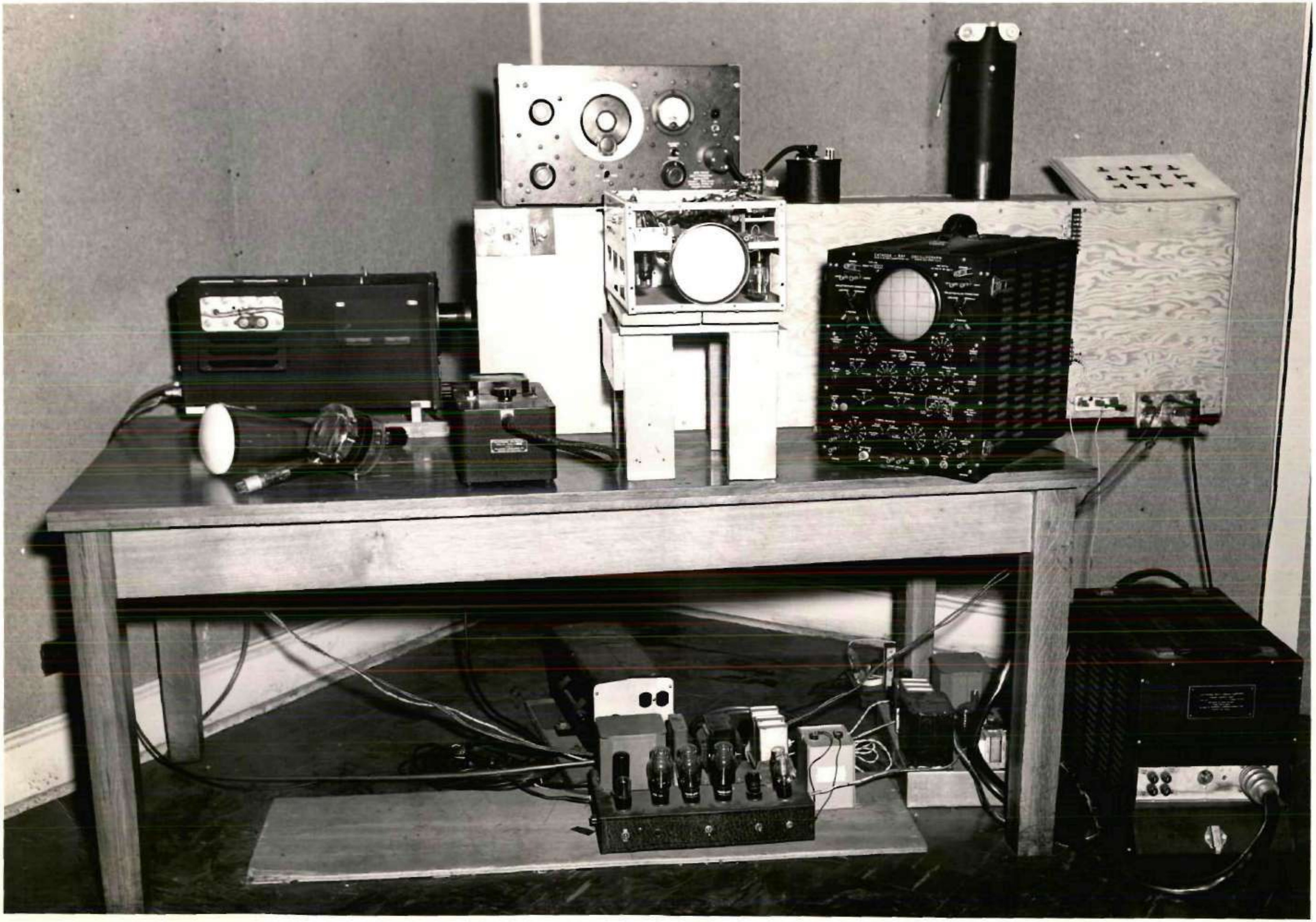


FIG. 1 TELEVISION SYSTEM AND ASSOCIATED EQUIPMENT

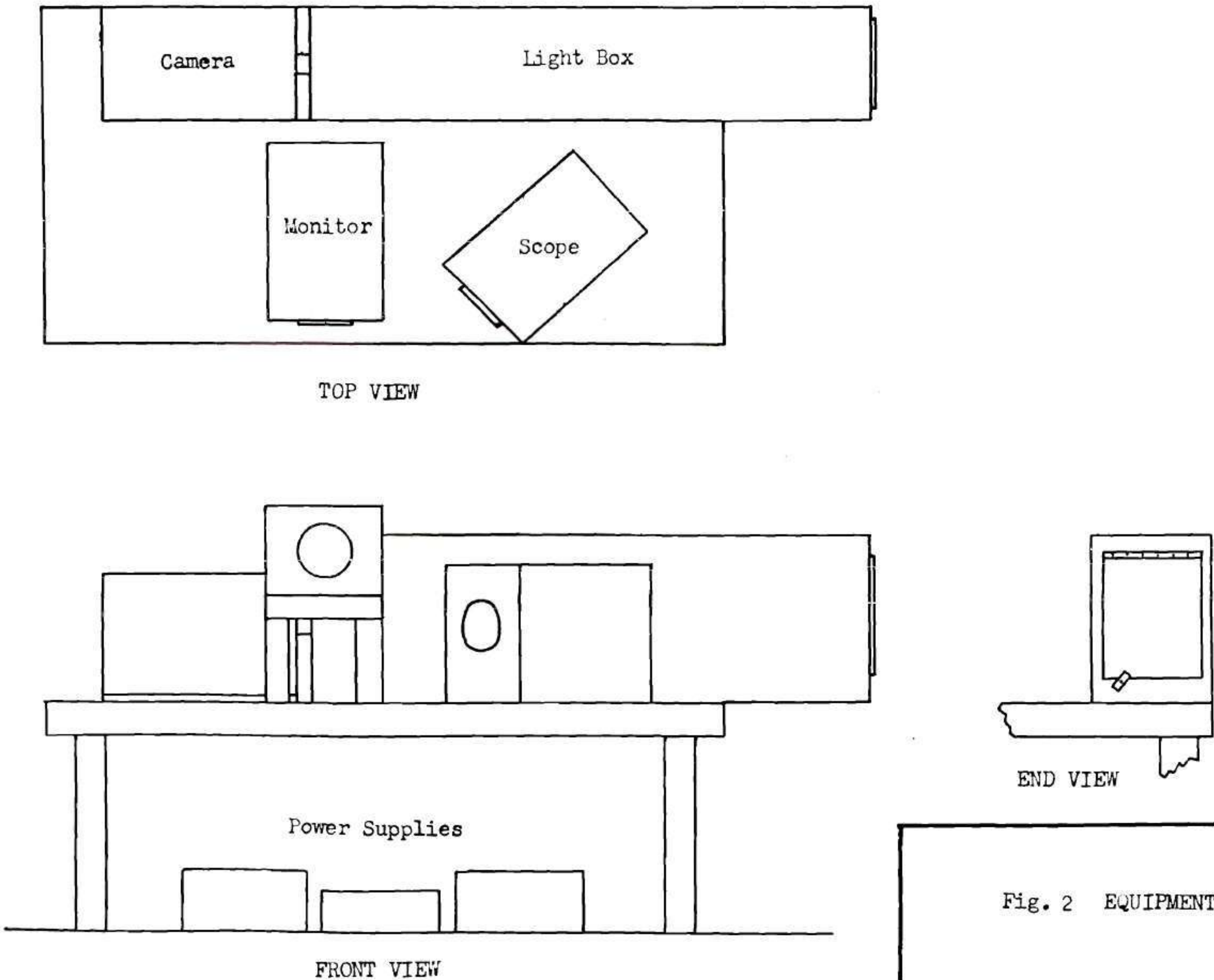


Fig. 2 EQUIPMENT LAYOUT

supplied with 28 volts d-c. This camera employs the Type 1846 iconoscope with magnetic deflection, followed by four stages of video amplification using the Type 1649 tube or its equivalent, the 12AC7. The next stage employs one triode of a 12SN7 driving the second triode of the 12SN7, which is cathode-coupled to the coaxial-cable transmission line.

Combination shunt and series compensation is employed in every stage except the cathode-coupled section, which is not compensated. The noise level is minimized by the use of a high grid resistance to couple the iconoscope to the first video stage. This form of coupling degrades the high-frequency response which is restored by a resistance-capacitance peaking circuit between the second and third video stages.

The monitor employs a Type 5BP4 kinescope with electrostatic deflection, using 2000 volts on the second anode. Its video section consists of a resistance-coupled 12AC7 stage driving a combination shunt and series compensated 12AG7.

Light Box

A long narrow box was constructed as shown in Figure 3 so the test charts could be presented to the camera under fixed conditions of illumination, distance, and focus. The box was built so that cards of a standard size could be inserted for presentation, and all test material was mounted on these cards. Eight auto headlight bulbs of 32 candle-power each were placed behind baffles to illuminate the test patterns without shining directly into the camera. Transformer operation was used for the lights since it was found not to introduce flicker. The illumination was measured over the presentation opening and was found

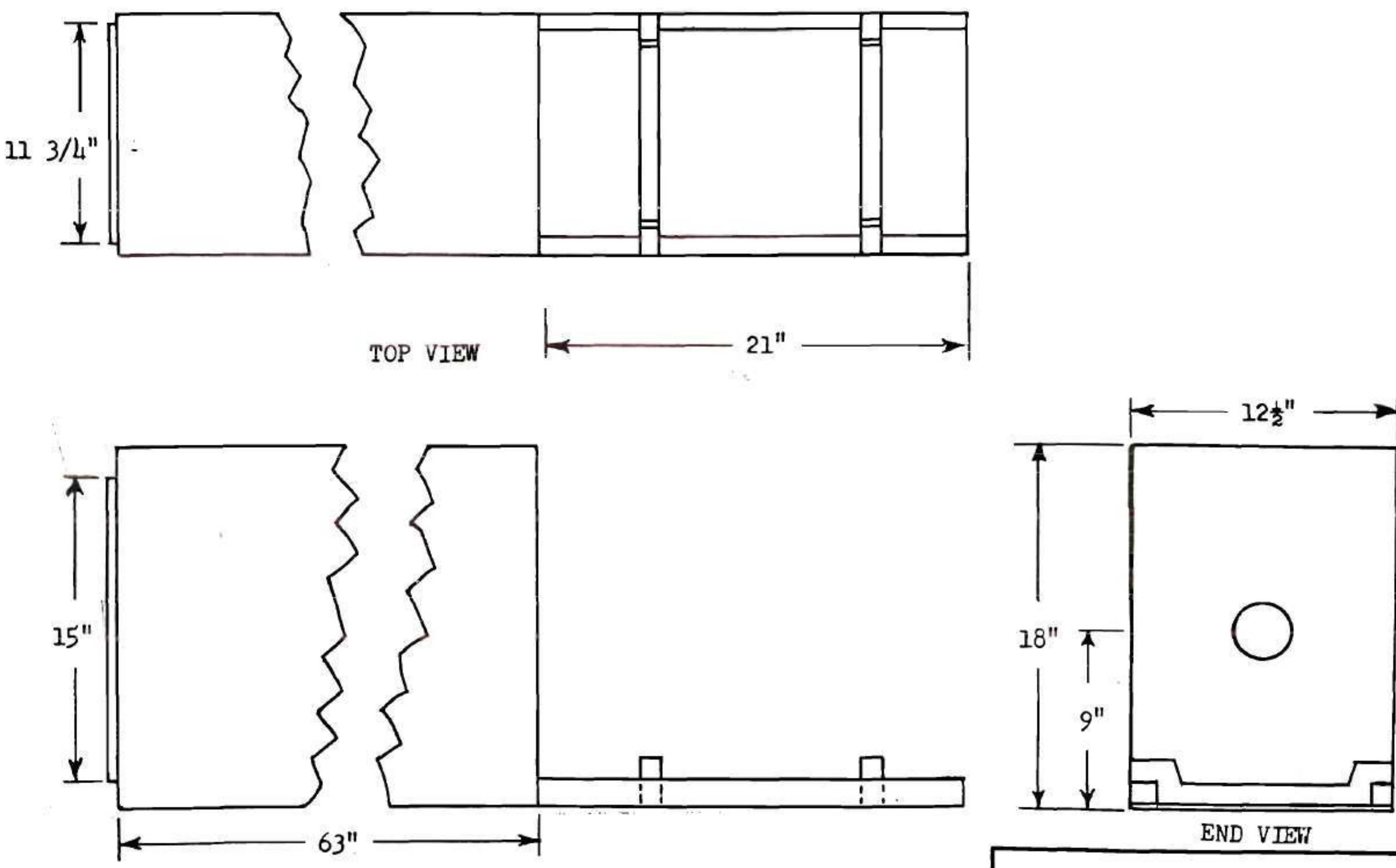


Fig. 3 LIGHT BOX

to be uniform within 10%.

Test Equipment

The following additional equipment was employed in the course of this thesis:

Dumont Wide-Band Oscillograph, Type 248.

General Radio Beat Frequency Oscillator, Type 700-A.

Ballantine Sensitive R. F. Voltmeter, Model 304.

General Radio Radio-Frequency Capacitance Bridge, Type 516-C.

MEASUREMENTS

Amplitude Characteristics Measurements

The amplitude response of the television system was determined with the oscillator and the electronic voltmeter using standard procedure. The input signal was fed to the grid of the first camera video stage, and the output signal of the system was taken from the kinescope grid. Care was exercised to insure that the waveform of the driving oscillator was pure, and precautions were taken to minimize noise, hum, and distortion of the input signal by the video system. Parasitic oscillations in the camera were isolated and suppressed. Great difficulty was experienced in eliminating an interfering external signal with a frequency of about 4 mc. This interference seemed less severe during rainy weather, so most of the measurements were made during that period.

The following circuit modifications were necessary prior to making the response measurements. The horizontal and vertical sweep multivibrator tubes were removed from their sockets to eliminate the synchronizing and blanking impulses from the camera output signal. The iconoscope was removed from its socket to prevent the stationary spot from damaging the mosaic. The monitor high-voltage supply was disconnected to prevent damage to the kinescope screen. (The kinescope was left in its socket so that it would load the circuit during the measurements to the same extent as when the system is in actual operation.) The high-peaking circuit was removed, since the first video stage was driven by a low-impedance source which minimized the effect of stray input capacitance.

Phase-shift Measurements

The phase response was determined with the oscilloscope and the oscillator. The input signal was applied directly to the horizontal deflection plates and the output signal was applied directly to the vertical plates of the oscilloscope. The oscillator frequency was read when the resulting ellipse closed into a straight line or opened into a circle to avoid the inaccuracy of estimating the dimensions of the ellipse. In this manner, frequency readings were obtained for every 90° of phase shift for the over-all system with its eight video stages.

Line and Field Frequency Measurements

The sweep frequencies were measured by comparing the saw-tooth deflection voltages with the oscillator signal on the oscilloscope.

Stray Capacitance Measurements

The stray capacitance of a resistance-coupled stage was measured by determining the frequency at which the response of the stage was 0.707 its mid-frequency response. At this frequency, the capacitive reactance due to the stray capacitance is equal to the load resistance of the stage.

Inductance and Capacitance Measurements

The capacitance bridge and its auxiliary equipment was employed to measure the value of inductances, capacitances, and stray coil capacitances.

CHANGE OF BAND-WIDTH

For the experimental phase of this research, the band-width of the television system was changed by discrete steps and the resolution corresponding to each band-width condition was determined. It would have been desirable to alter identically a large number of video stages for each band-width condition to simulate an actual television system. However, in order to simplify the test procedure, only one stage (termed the "modified stage") was changed. The frequency response of the rest of the system was uniform out to a high frequency so that the response of the modified stage determined the response of the over-all system.

Initially the band-width was limited by the addition of shunt capacitance across the load resistance of the uncompensated modified stage. This seemed to be a logical approach to the problem, since the response of a resistance-coupled amplifier is restricted by the stray capacitance from its plate to ground. However, preliminary tests indicated that this method was not satisfactory over a large range of resolution due to the nature of the distortion introduced by the shunt capacitance.

It became apparent that significant results would be obtained only if the amplitude and phase characteristics of the experimental television system were similar in shape to those used in actual systems. With this goal in view, shunt-compensated coupling networks were designed and constructed which gave the modified stage, and therefore the entire system, the desired response. Each network consisted of an inductance and a capacitance on a bakelite base mounted on three banana plugs, constructed so that it could be inserted in the circuit and removed without turning off the power supply.

The desired response was obtained by adding shunt capacitance across the plate load of the modified stage and compensating for it just as though it were stray capacitance. The design formulas for shunt compensation are as follows:[1]

$$K = R\sqrt{C/L} \tag{1}$$

$$f_o = 1/(2\pi\sqrt{LC}) \tag{2}$$

The load resistance is denoted by R, the shunting capacitance is C, and L is the compensating inductance. The parameter K will be recognized as $1/Q$, and the design frequency, f_o, is seen to be the resonant frequency of the series R-L-C circuit. The value of K alone determines the shape of the characteristic curves. The value for f_o places the curves properly on the frequency spectrum. These formulas are normally used to determine the inductance required to compensate for the stray capacitance from plate to ground. However, since they are completely general, the formulas may be used to find the shunt capacitance needed to <u>reduce</u> the amplitude response, and to find the inductance required to give the desired shape of the amplitude response curve. The only qualification imposed is the limitation that R must be chosen small enough so that the desired shunt capacitance will not be less than the stray capacitance C_s, because C_s cannot be reduced.

Equations (1) and (2), after combining and eliminating L, can be

---

[1]A. V. Bedford and G. L. Fredendall, "Transient Response of Multistage Video-Frequency Amplifiers," Proc. I.R.E., Vol. 27, April, 1939.

written as:

$$f_o = K/(2\pi RC)$$

or

$$C = K/(2\pi Rf_o) \tag{3}$$

Rewriting Equation (1),

$$L = (R^2/K^2)C \tag{4}$$

For given values of K, R, and f_o, Equation (3) gives the total shunt capacitance, C. The value of L corresponding to this C is given by Equation (4). As the C in Equation (3) is the total shunt capacitance, the stray capacitance must be subtracted to determine the added capacitance, C_a. That is,

$$C_a = C - C_s \tag{5}$$

This design procedure is illustrated in Figure 4. The equivalent circuit is shown for a resistance-coupled radio-frequency amplifier stage in Figure 4a. In Figure 4b, C_a is shunted from plate to ground and L is inserted to compensate for the effect of the total shunting capacitance. If C_s and C_a are lumped together as in Figure 4c, the resulting circuit will have the same configuration as the compensated circuit to which Equations (1)-(4) apply. The removable coupling network is indicated in the circuit diagram in Figure 4d. The component connections are shown in Figure 4e, and the construction is illustrated in the last figure.

These networks are shown in Figure 5 and will be referred to as

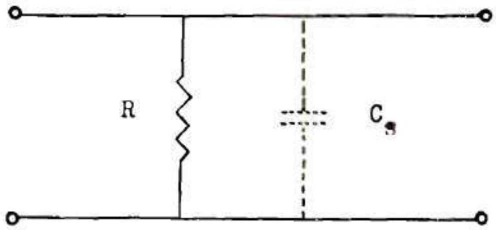


Fig. 4a EQUIVALENT CIRCUIT

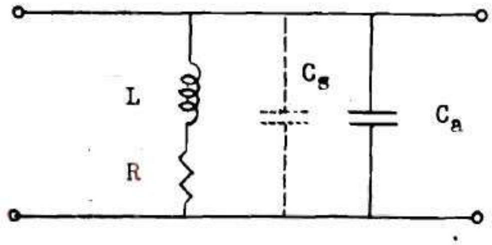


Fig. 4b INDUCTANCE AND CAPACITANCE ADDED

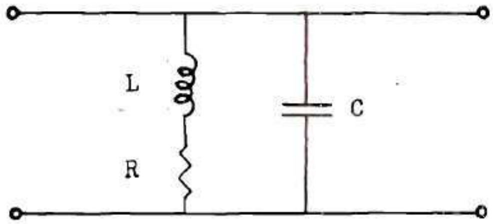


Fig. 4c

STRAY AND ADDED CAPACITANCE LUMPED

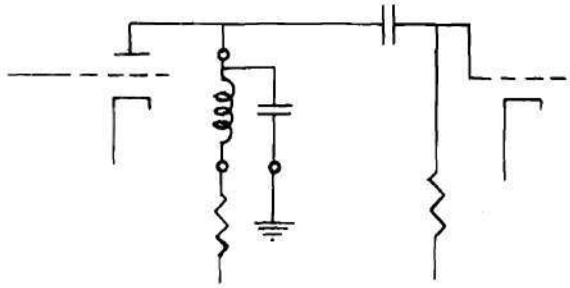


Fig. 4d COUPLING NETWORK IN CIRCUIT

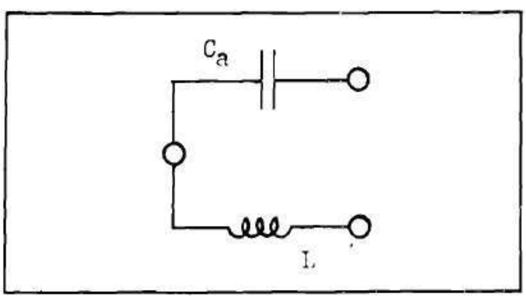


Fig. 4e

COMPONENT CONNECTIONS ON NETWORK

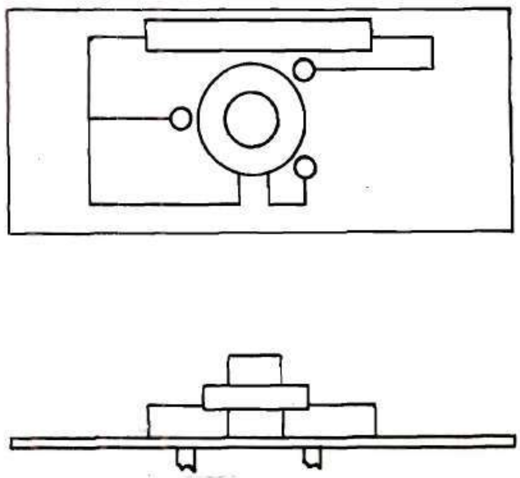


Fig. 4f CONSTRUCTION OF NETWORK

Fig. 4 DESIGN OF COUPLING NETWORKS

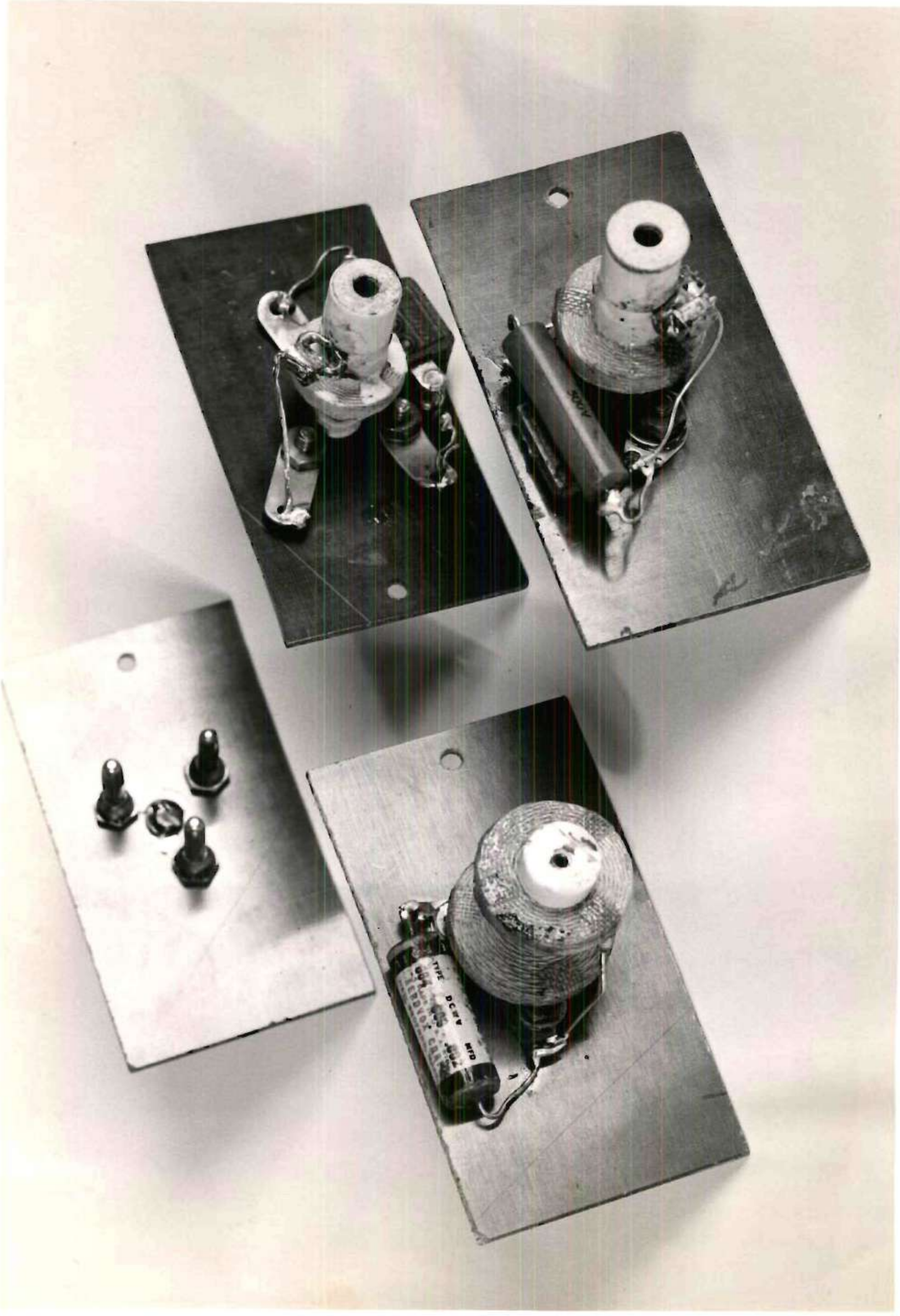


FIG. 5 COMPENSATED COUPLING NETWORKS

Net A, Net B, Net C, and Net D.[2] The largest band-width is obtained with Net A.

These networks performed quite satisfactorily, with slight inaccuracies in the component values having little effect on the shape of the response curves. (This is one advantage of shunt compensation over series and series-shunt compensation.) The amplitude characteristic curves are shown in Figure 6 for the modified stage coupled by these original networks. When the complete video chain was tested, several of the networks were experimentally altered to improve the response of the over-all system. The resulting over-all amplitude and phase response curves are shown in Figures 7 and 8.[3] These four band-width conditions which correspond to the four networks will be referred to as Condition A, Condition B, Condition C, and Condition D.

---

[2]The component values and design data are given in Appendix I.

[3]Figures 6, 7, and 8 are plotted from data presented in Appendix II.

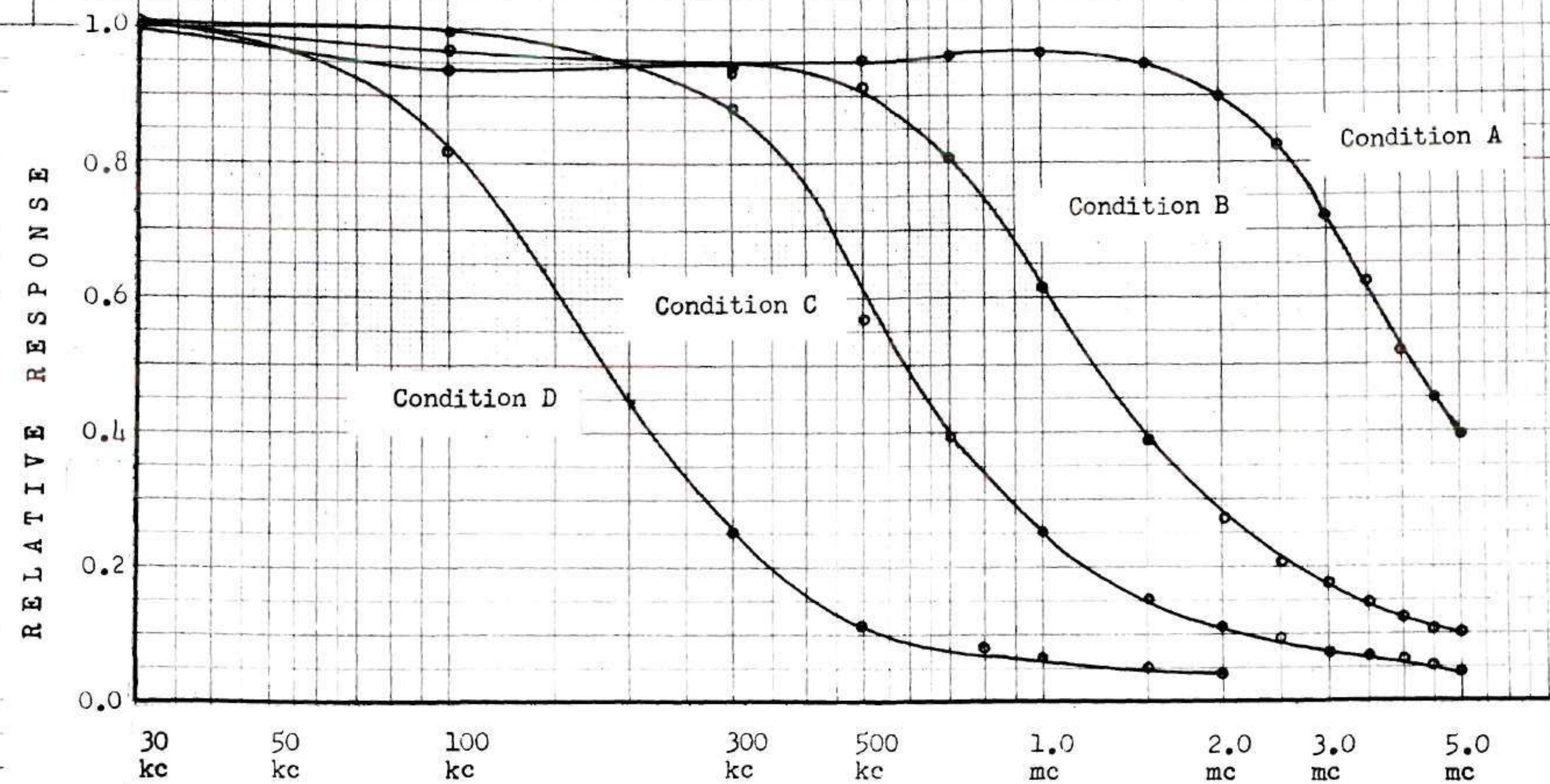


Fig. 6 AMPLITUDE CHARACTERISTIC CURVES FOR MODIFIED STAGE UNDER FOUR BAND-WIDTH CONDITIONS

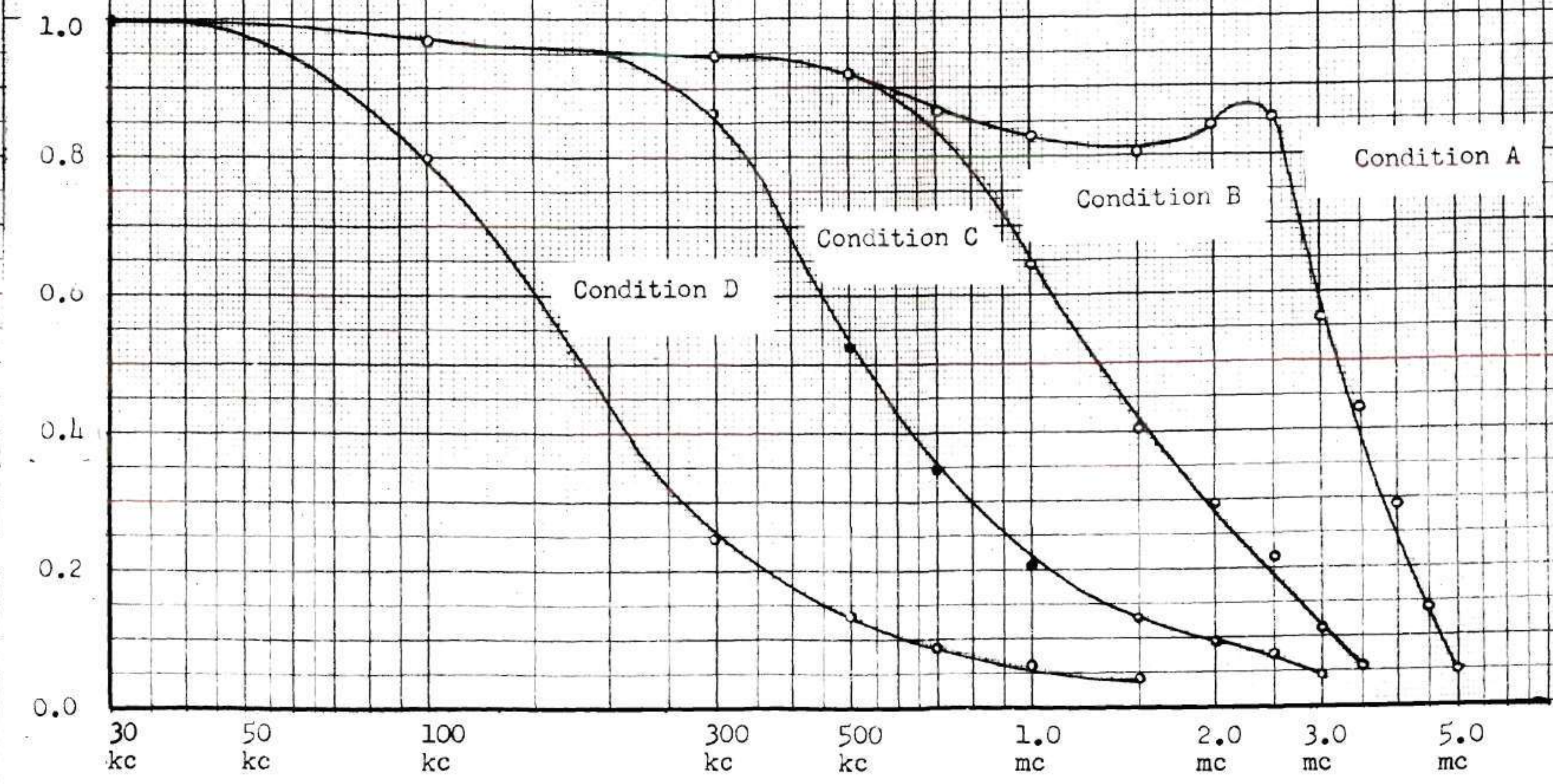


Fig. 7 AMPLITUDE CHARACTERISTIC CURVES FOR OVER-ALL SYSTEM UNDER FOUR BAND-WIDTH CONDITIONS

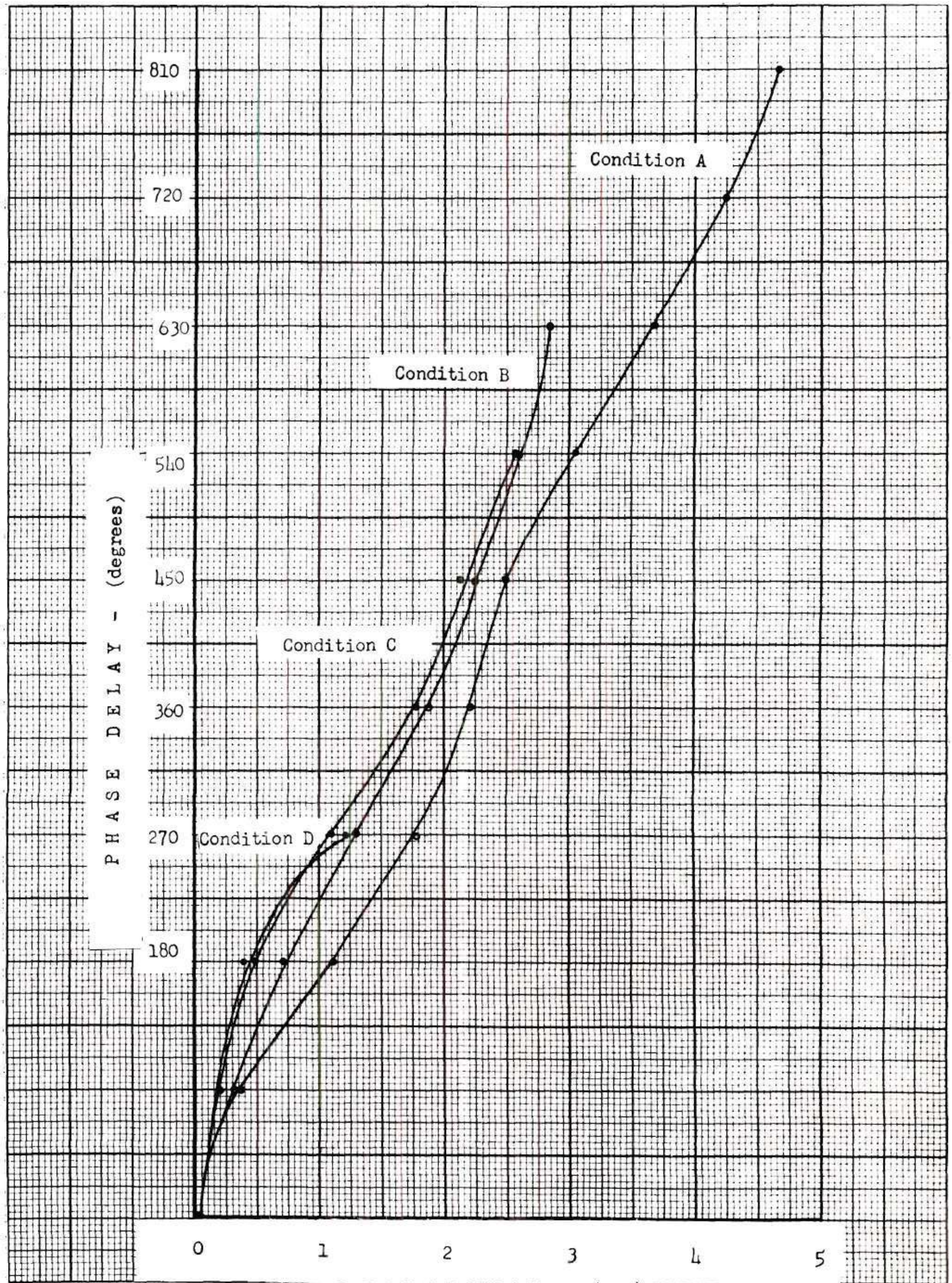


Fig. 8 PHASE CHARACTERISTIC CURVES FOR OVER-ALL SYSTEM UNDER FOUR BAND-WIDTH CONDITIONS

PRINCIPLES OF PICTURE TRANSMISSION

A television picture is not transmitted in its entirety but is sent point by point at such a rate that the persistence of the screen and the persistence of vision blends it into a continuous image. The sending and receiving spots are at all times at corresponding positions on their respective screens. At any one instant the only information transmitted is that describing the brightness of the particular area under the sending spot. As the spot moves along the scanning line at a constant velocity a signal is generated which is proportional to the brightness along the line. Thus any change in brightness in the horizontal direction causes high-frequency signals to be generated, while a change of brightness in the vertical direction causes signals of much lower frequencies to be generated. Horizontal resolution is therefore discussed from the standpoint of transmission of high frequencies, and the vertical resolution is discussed from the standpoint of transmission of much lower frequencies.[1] This thesis is concerned only with the horizontal resolution.

It has been shown that any change in brightness may be considered as the superposition of a number of abrupt transitions of brightness.[2] An abrupt transition or "step" of brightness may therefore be examined as the most elementary of all possible signals and also the most difficult

---

[1]S. W. Seeley and C. N. Kimball, "Analysis and Design of Video Amplifiers," Part II, RCA Review, January, 1939.

[2]A. V. Bedford and G. L. Fredendall, "Transient Response of Video-Frequency Amplifiers," Proc. I.R.E., Volume 27, April, 1939.

to transmit. Figure 9 illustrates how a rectangular pulse may be synthesized by treating it as the difference between two steps of brightness of infinite duration.

A moving object will, in general, generate a non-repetitive signal. This form of information may be analyzed using the Fourier Integral[3]

$$E(t) = \int_{-\infty}^{\infty} S(w)N(w)\cos wt \cdot dw$$

The frequency spectrum of the generated signal is $S(w)$, the transmission characteristic of the system is given by $N(w)$, and $w = 2\pi \cdot$(repetition frequency). From this analysis the signal generated by the brightness step is seen to contain all frequencies from zero to infinity. The ability of the television system to transmit these frequencies in their proper amplitude and phase is a direct measure of the success of the system in reproducing the transition. The resulting frequency spectrum has been determined for some special cases,[4] but in general this method does not lend itself to numerical or graphical solution.

A more useful method is applicable when the object is stationary, as then a repetitive signal of frame frequency is generated. Using the frame frequency as the repetition frequency, the general expression for the video signal has been developed by Fourier Analysis.[5] As this series contains only harmonics of the fundamental frequency, a finite number of

---

[3] E. A. Guillemin, Communication Networks, Volume II, (John Wiley and Sons, Inc., New York, 1935), p. 461.

[4] *Loc. Cit.*

[5] Mertz and Gray, *Op. Cit.*

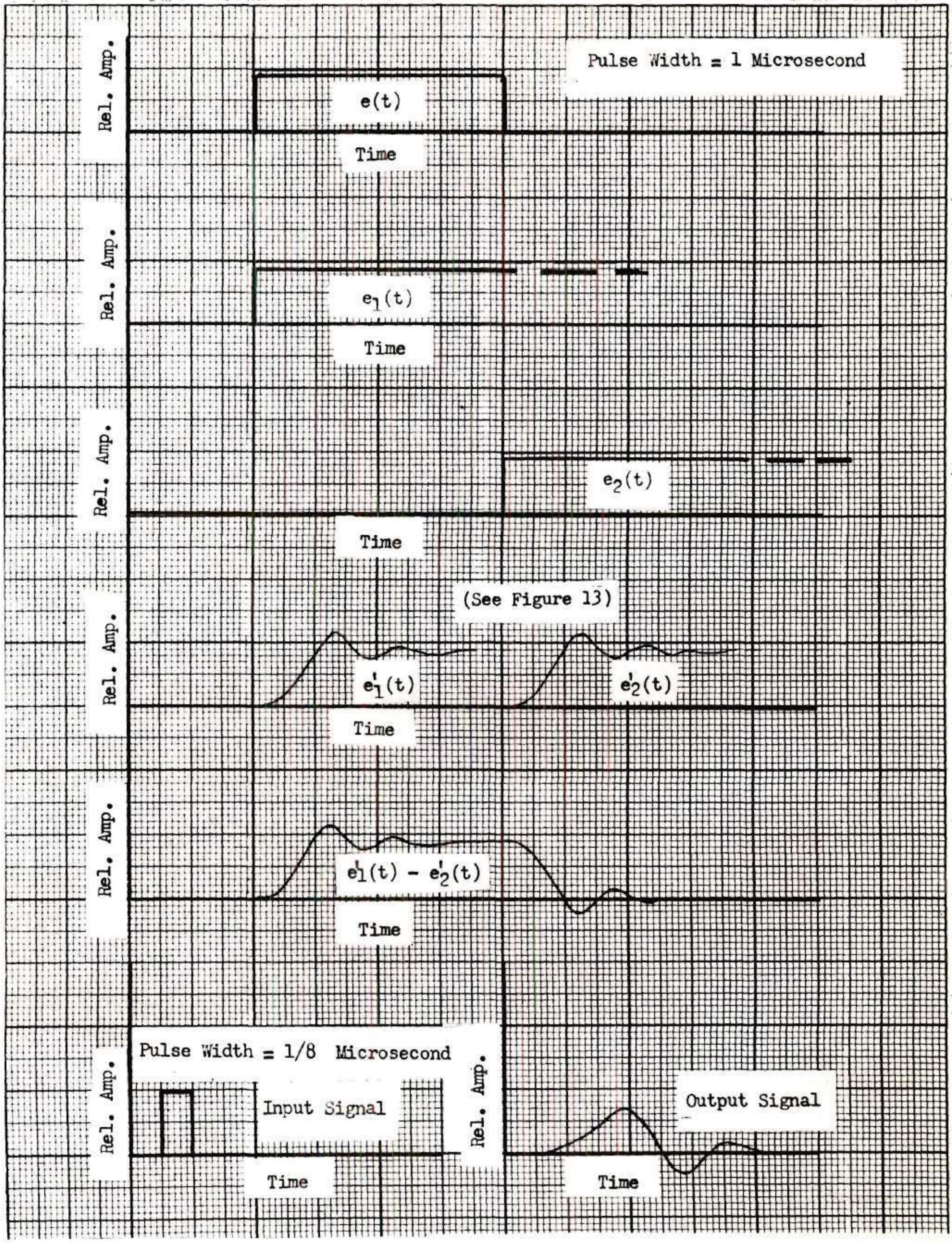


Fig. 9 RESPONSE OF VIDEO STAGES TO LONG PULSE AND SHORT PULSE SYNTHESIZED BY SUPERPOSITION

terms may be considered as an approximation for the purpose of numerical computation. As an important special case of a signal generated by a stationary object, the square wave may be considered. The signal may be represented as follows:

$$e(t) = 1/2 + 2/\pi \left\{ \sin w_o t + 1/3 \sin 3w_o t + 1/5 \sin 5w_o t \ \ldots \right\}$$

$$\text{where } w_o = 2\pi s \ (\text{frame frequency})$$

When this signal is passed by a system with amplitude characteristics A_k and time delay D_k, its form becomes:

$$e'(t) = 1/2 + 2/\pi \left\{ A_1 \sin w_o(t-D_1) + A_3/3 \sin 3w_o(t-D_3) + \ldots. \right\}$$

If a sufficient number of terms are considered so that the effect of the neglected terms is very small, the transient response of a system to the square wave may then be computed when the steady-state characteristics have been calculated or measured. The response of single-stage and multi-stage amplifiers has been evaluated in the literature using this method.[6]

As may be seen from the preceding series, an ideal amplifier is one with a constant amplitude characteristic and with a constant time delay for all frequencies. The effect of imperfect amplitude and phase characteristics has been discussed in the literature.[7] In brief, poor high-frequency amplitude characteristics result in the rounding off of

---

[6] A. V. Bedford and G. L. Fredendall, "Transient Response of Video-Frequency Amplifiers," Proc. I.R.E., Volume 27, April, 1939.

[7] Donald G. Fink, Radar Engineering, (McGraw-Hill Book Company, Inc., New York and London, 1947), p. 123.

transition edges and an increase in the time of rise of steep wave fronts. This produces only symmetrical distortion of the signal. Poor phase characteristics result in a skewing of the signal, that is, in nonsymmetrical distortion.

THE TELEVISION SYSTEM

A complete television system is composed of three essentials; the scanning spot in the pick-up tube, the transmission channel, and the reproducing spot in the kinescope. For convenience, the scanning spot in the pick-up tube will be referred to as the sending spot, and the spot in the kinescope will be referred to as the receiving spot. The coordinates for the field will be X, Y and those for the spot will be x, y.

Pick-up Tube

Since the scanning process has a detrimental effect upon the horizontal resolution, it will be discussed in detail. Theoretically, the scanning spot is circular in cross-section and has an error-function distribution.[1] Its sensitivity is given by

$$S(x,y) = K_1 e^{-kr^2}$$

The sensitivity of the spot[2] at a distance r from its center is denoted by S. This function is plotted in Figure 10 in terms of the spot radius b, which is arbitrarily defined by expressing the sensitivity as

$$S(x,y) = K_1 e^{-\pi r^2/b^2}$$

The sensitivity of the spot along the horizontal scanning line,

---

[1] V. K. Zworykin and G. A. Morton, Television, (John Wiley and Sons, Inc., New York, 1940), p. 372.

[2] The sensitivity S is written as S(x,y) to indicate that it is a function of both the vertical and horizontal distances from the spot center. This form of notation is followed throughout this discussion.

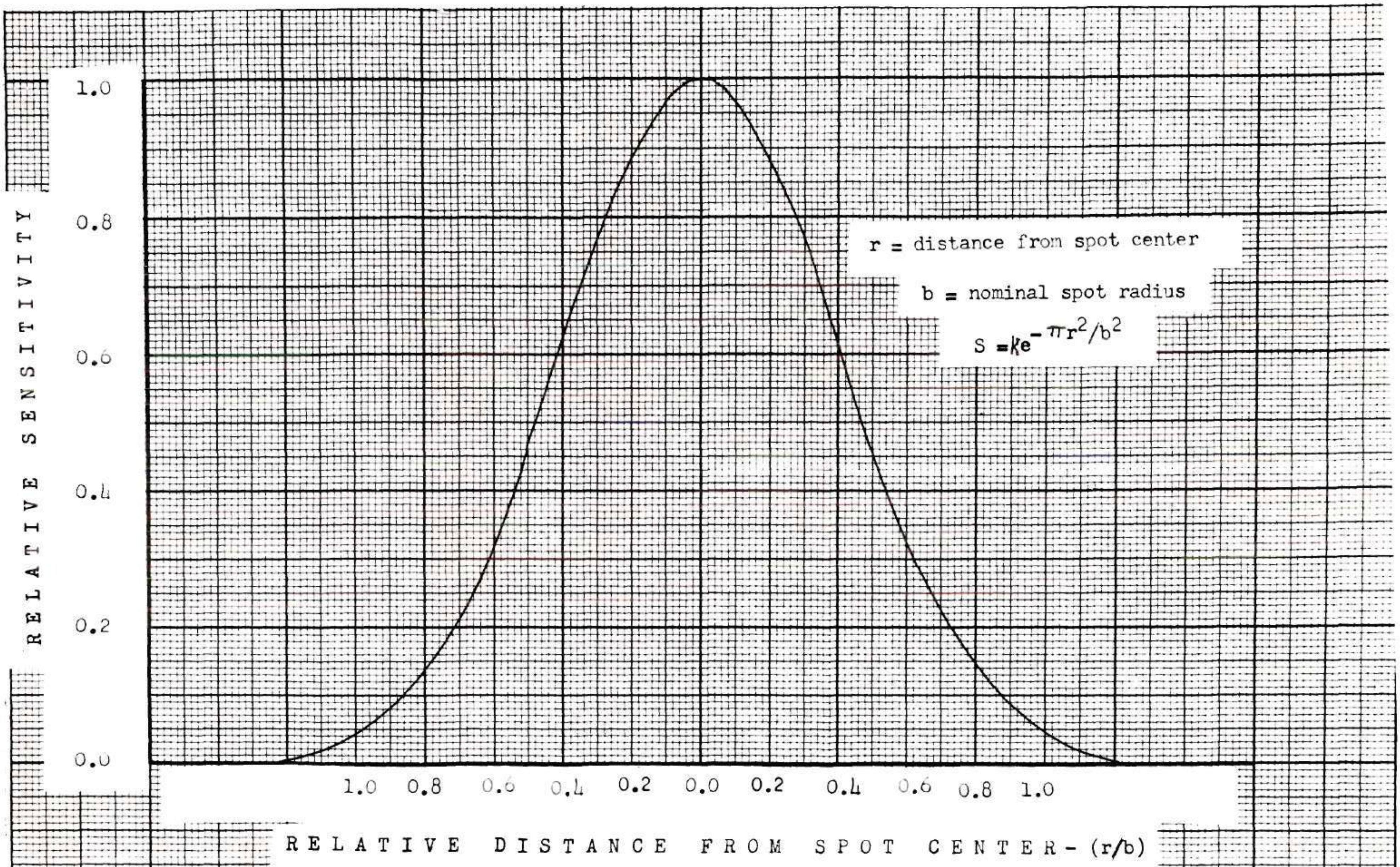


Fig. 10 SENSITIVITY OF SCANNING SPOT

S', has the same distribution. That is,[3]

$$S'(x) = K_2 e^{-\pi x^2/b^2}$$

Let us examine the signal generated as the sending spot traverses the field. The signal generated by the spot is proportional to the product of the sensitivity of the spot and the brightness under it. That is,[4]

$$\Delta e(X) = K_3 S'(x) B(X + x)\Delta x$$

or

$$e(X) = K_3 \int_{-\infty}^{\infty} S'(x) B(X + x)dx \qquad (1)$$

The position of the spot on the scanning line is represented by X, and B(X + x) gives the brightness of the field at a distance x from the spot center.

We have stated that the ability of the video system to transmit an abrupt transition is an indication of the system's resolution. If the special case of a step change from zero brightness to a constant brightness B_1 is considered, Equation (1) reduces to

$$e(X) = K_3 B_1 \int_{X_1-X}^{\infty} S'(x)\, dx \qquad (2)$$

---

[3]This relationship is derived in Appendix III.

[4]Zworykin and Morton, Op. Cit., p. 183.

The abscissa of the step change of brightness is denoted by X_1. The transient response of the sending spot to the step change in brightness is shown in Figure 11.[5] It will be noted that the response is symmetrical, implying an absence of phase distortion.

Mertz and Gray have shown that the aperture distortion has the same form as the attenuation of an electrical filter.[6] The amplitude characteristic $Y(k)$ of an aperture with sensitivity $S'(x)$ along the scanning line is given by:

$$Y(k) = \int_{-\infty}^{\infty} S'(x)\cos\,(2\pi kx/Wn)dx \qquad (3)$$

where k is the number of the harmonic of the frame frequency in the Fourier Series representing the brightness of the screen, W is the screen width, and n is the number of lines per field. The amplitude characteristic curve for a spot of typical size for use in the iconoscope is shown in Figure 12. For comparison, the characteristics are shown for a spot of twice its diameter.[7] Amplitude characteristics for spots of other shapes,[8,9,10] and discussions of "zero frequencies" and equalization

---

[5]Equation (2) is derived from Equation (1) and data for the curve is presented in Appendix IV.

[6]Mertz and Gray, Op. Cit.

[7]This information is obtained from Equation (3) and data for the curve is presented in Appendix V.

[8]Mertz and Gray, Op. Cit.

[9]Zworykin and Morton, Op. Cit., p. 183.

[10]O. H. Schade, "Electro-Optical Characteristics of Television Systems," Part II, RCA Review, Volume 9, June, 1948, p. 246.

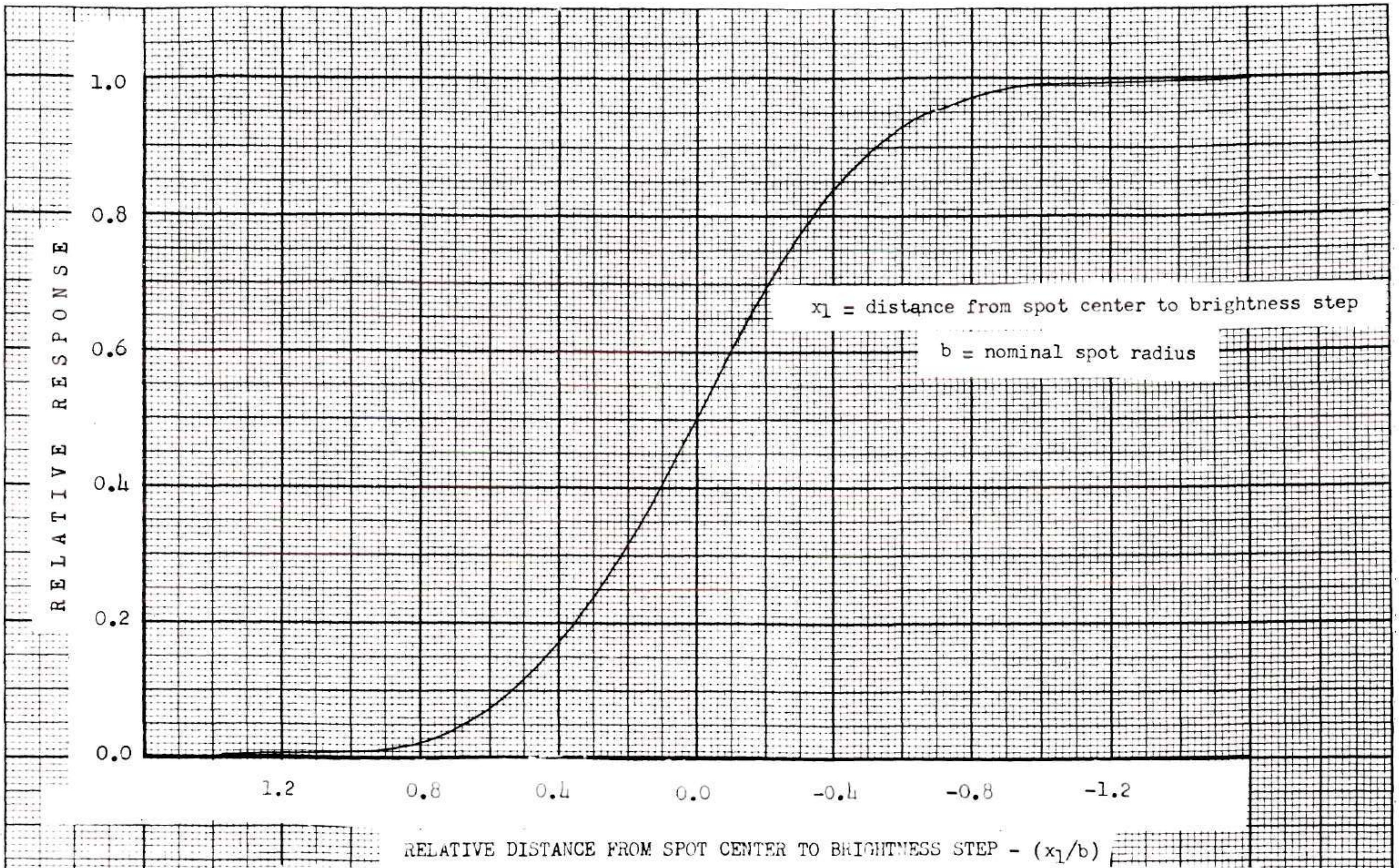


Fig. 11 SIGNAL GENERATED AS SCANNING SPOT TRAVERSES ABRUPT CHANGE OF BRIGHTNESS

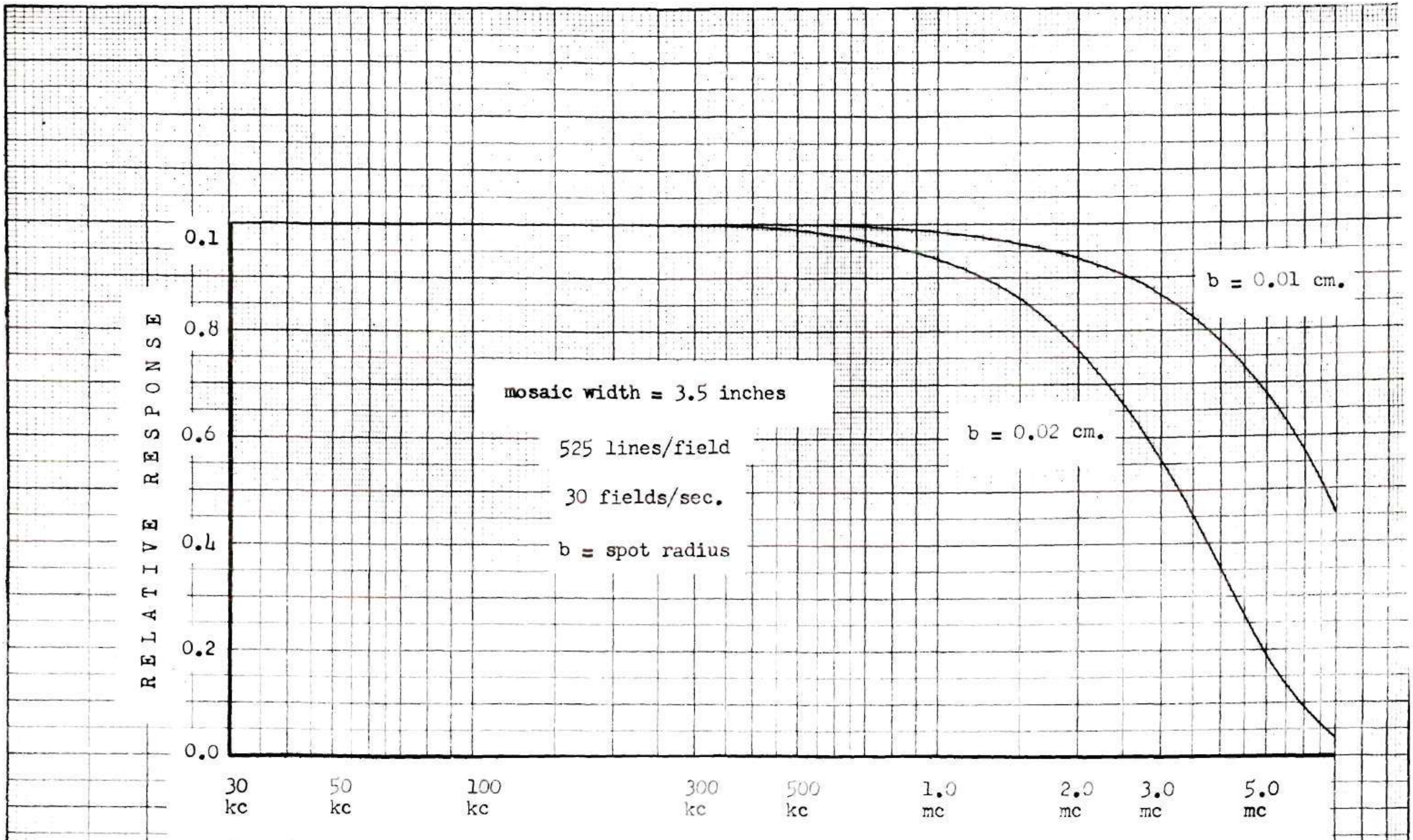


Fig. 12 AMPLITUDE CHARACTERISTIC CURVE OF SCANNING SPOT

of aperture distortion[11] may be found in the literature.

Transmission Channel

Only the video amplifier is discussed in this paper. The problems introduced by transmission lines, intermediate-frequency and radio-frequency stages, modulation and demodulation, antennas, and propagation are omitted. The admittance of the stray capacitance of a video stage causes loss of high-frequency response. Compensation for this loss has been extensively discussed in the literature.[12,13,14] An expression may be derived which gives the response of a video stage utilizing a simple form of compensation, as a function of the design parameters.[15]

The over-all response of a number of identical stages in cascade may be conveniently found if the response of an individual stage is known.

If the amplitude and time delay of one stage are given by A_f and D_f respectively, the amplitude and the delay for N identical stages will be $(A_f)^N$ and ND_f. The amplitude and phase characteristics of 16, 32, and 64 stages have been found for several degrees of compensation.[16] To find the transient response of N stages to a step function, it is

---

[11] Wilson, Op. Cit.

[12] S. W. Seeley and C. N. Kimball, "Analysis and Design of Video Amplifiers," RCA Review, Volume II, October, 1937.

[13] S. W. Seeley and C. N. Kimball, "Analysis and Design of Video Amplifiers," Part II, RCA Review, Volume III, January, 1939.

[14] E. W. Herold, "High Frequency Correction in Resistance-Coupled Amplifiers," Communications, August, 1938.

[15] P. M. Seal, "Square-Wave Analysis of Compensated Amplifiers," Proc. I.R.E., Volume 37, January, 1949, p. 48.

[16] A. V. Bedford and G. L. Fredendall, "Transient Response of Multi-stage Video-Frequency Amplifiers," Proc. I.R.E., Volume 27, April, 1939.

permissible to employ a Fourier Series, assuming a square-wave input signal with a half-period long enough to permit the output signal to reach its steady-state value.[17] The response of a video amplifier with 64 stages is shown in Figure 13. A technique for synthesizing the transient response from steady-state characteristics is discussed in the literature which may be useful in reducing the labor involved in performing the lengthy calculations.[18]

Kinescope

Receiving spot considerations follow closely those of the sending spot. As its beam current must be much larger than the beam current of the sending spot, it is to be expected that the receiving spot will be larger than the sending spot. Since a larger screen is used in the kinescope, a larger receiving spot is permissible, for the aperture distortion is a function of the ratio of the spot size to the screen width. This ratio is practically equal for recommended values of iconoscope and kinescope spot sizes.

There are other factors which limit the performance of the kinescope.[19,20] Due to total internal reflections inside the glass face of the tube, the detail contrast is limited to a rather low value.

---

[17] Loc. Cit.

[18] A. V. Bedford and G. L. Fredendall, "Analysis, Synthesis, and Evaluation of the Transient Response of Television Apparatus," Proc. I.R.E., Volume 30, October, 1942.

[19] R. R. Law, "Contrast in Kinescopes," Proc. I.R.E., Volume 27, August, 1939, p. 511.

[20] C. H. Bachman, "Image Contrast in Television," General Electric Review, September, 1945, p. 13.

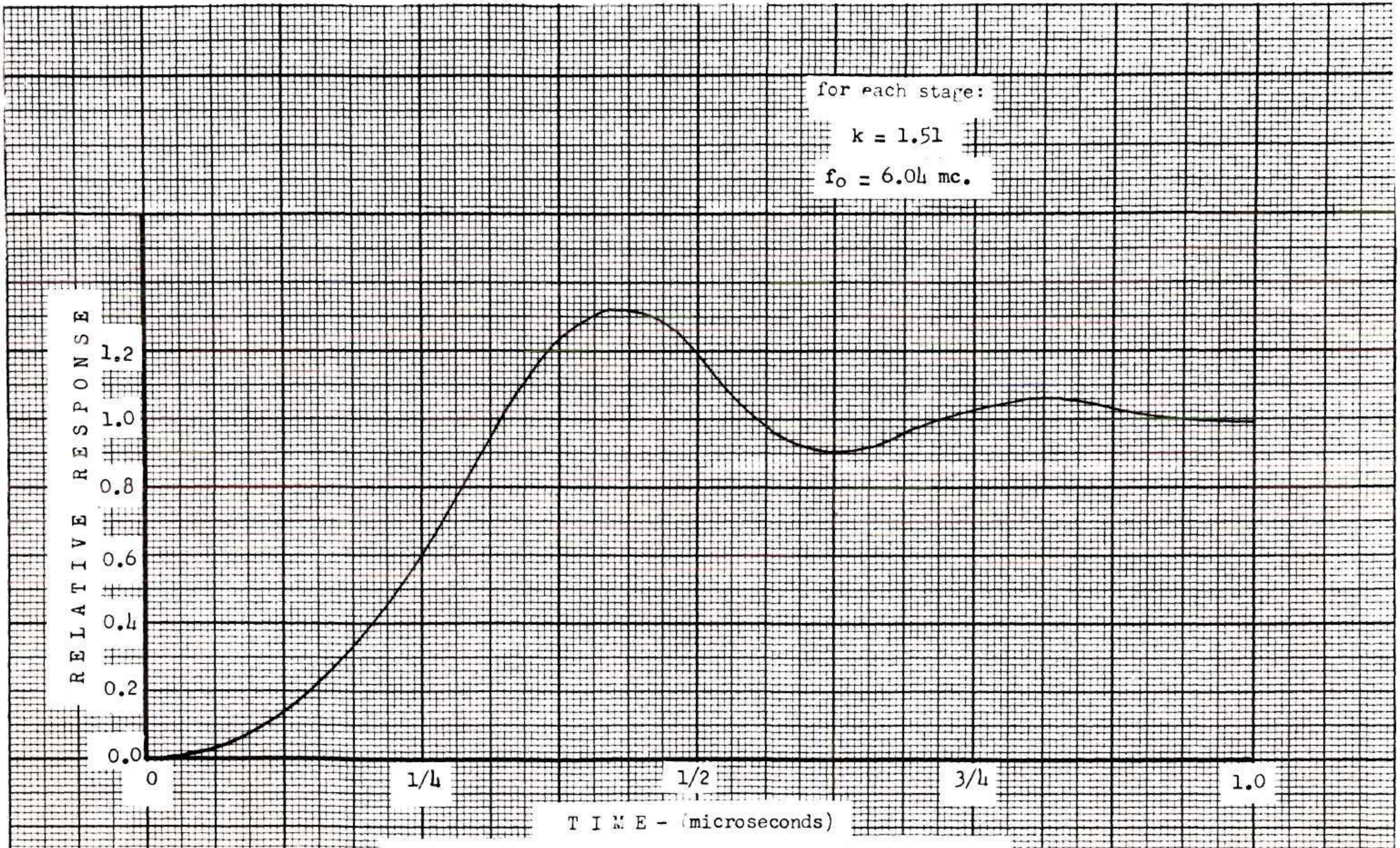


Fig. 13 RESPONSE OF 64 STAGES TO STEP FUNCTION

Light reflected from the interior of the tube and from the screen face lowers the over-all contrast. Secondary emission also has a detrimental effect. These last two difficulties have been minimized with the introduction of metalized screens.[21]

---

[21]D. W. Epstein and L. Pensak, "Improved Cathode-Ray Tubes with Metal-Backed Luminescent Screens, RCA Review, March, 1946.

RESOLUTION

Introduction

To properly interpret the value of information transmitted by the television system, we must examine the manner in which the eye responds to this information.

Let us take, as a basic test of resolution, the minimum separation with which two parallel bars can be resolved. Three different cases are considered.

Case I

In this case the bars and background are of maximum contrast. This is the condition for optimum resolution. Therefore the minimum separation will be limited by the visual acuity, which is determined by the angle subtended by the receptors (rods and cones) in the retina of the eye. On the average, a receptor subtends a visual angle of 1 minute in the sensitive region of the eye. (This sensitive region, termed as the "fovea centralis" covers an angle of about 1° or 2° in the center of the retina.) Therefore the bars can be resolved when they are separated by an angle of one minute, as there is one unstimulated receptor between two stimulated ones.[1]

Case II

For the second case, consider the two bars on a gray background, that is, the same as Case I but with lower contrast. Then, even though

---

[1]M. Luckiesh and F. K. Moss, The Science of Seeing, (Van Nostrand Company, New York, 1937), p. 64.

their separation is greater than one minute of visual angle, there are contrast levels below which they will not be resolved, since more separation is required between the bars when the contrast is lower. This relationship has been explored experimentally in extensive tests and the results presented in empirical curves relating the contrast, separation, brightness, and exposure time to the threshold resolution.[2] The test object employed was a pair of parallel bars. Very thorough studies have also been made to determine the visibility of a circular area on a background of different brightness.[3] In short, the question of visibility of an area of uniform brightness on a background of uniform brightness of a different level has been satisfactorily investigated experimentally.

Case III

This case deals with the resolution of two dark bars of non-uniform brightness which fade into a background of non-uniform brightness. Apparently this important case has not received the careful attention accorded the preceding ones, although it has been mentioned in the literature.[4,5]

Case III, Additional Considerations

A study of the horizontal resolution of a television image requires

---

[2] Ibid., p. 124.

[3] H. R. Blackwell, "Contrast Thresholds of the Human Eye," Journal of the Optical Society of America, Volume 36, November, 1946, p. 624.

[4] J. C. Wilson, Television Engineering, (Pitman & Sons, Ltd., London, 1937), p. 91.

[5] O. H. Schade, "Electro-Optical Characteristics of Television Systems," Part I, RCA Review, Volume 9, March, 1948, p. 26.

consideration of Case III. The brightness of areas reproduced by a television system always changes gradually due to imperfect transmission of the video signal. This imperfect transmission results in loss of abruptness of the transition from one brightness level to another as shown in Figures 11 and 13. The determination of the visibility of the individual scanning lines is also a problem of the resolution of areas of non-uniform brightness.

The results obtained by several authors from experimental approaches to related problems will now be presented.

Rayleigh[6,7] states that two bars can be resolved if the brightness of the intervening area is less than 0.8 of the brightness of either bar. However, this criterion was secured from consideration of a rather special case and must not be generalized, because the resolution also depends upon the separation, adaptation brightness, and the shape of the brightness curves.

Using photographs having a line structure similar to that of facimile reproductions, Wilson[8] and Harries[9] reported that scanning lines can be resolved by the average observer when separated by an angle greater than about 2.3 minutes.

---

[6] J. C. Wilson, Op. Cit., p. 22, 93.

[7] J. W. Rayleigh, "Investigations in Optics," Philosophical Magazine, 5th Series, Volume 8, October, 1879, p. 266.

[8] J. C. Wilson, Op. Cit., p. 99.

[9] As referred to by Wilson, Loc. Cit. (J.H.O. Harries, " A Quantitative Analysis of Television," Television, Volume 2, p. 108.).

Engstrom[10] concluded the minimum separation angle for resolution of detail was about 1.5 minutes by projecting motion pictures through a multiple-lens system which created the effect of a television line structure.

The results obtained by these authors depended upon the type of test material employed, the methods of presentation and observation, and upon the objectives of their research.

The Appraisal of Image Reproduction

Many approximate expressions have been proposed for the evaluation of the resolution of a television system. The primary need for this information originated in the selection of the proper number of lines in a television system to give equal vertical and horizontal resolution. In general, these criteria are based upon the reproduction of some element of detail and the evaluation of the accompanying distortion. The treatments of several authors will now be summarized.

Wheeler and Loughren[11] define the "width of confusion" as "... the width of a uniform band of light whose brightness is equal to the peak brightness of the reproduction of a very narrow line, and whose total light flux is equal to that of the reproduction." By neglecting phase distortion and applying Fourier Integral methods, they show that the width of confusion is inversely proportional to the nominal cut-off frequency.

---

[10] E. W. Engstrom, "A Study of Television Image Characteristics," Proc. I.R.E., Volume 21, December, 1933, p. 1631.

[11] H. A. Wheeler and A. V. Loughren, Op. Cit.

By considering a linear transition with the same subjective effect as an actual transition, Bedford and Fredendall[12] define the "width of blurring" as the distance (or time) required by the linear transition to achieve the full value of the change in brightness. The input signal is a unit change in brightness. This width of blurring is inversely proportional to the frequency.

Wilson[13] has calculated the "distortion area" of a reproduced step function for different cut-off frequencies of the transmission channel. The distortion area is defined as the difference in areas between the actual transition and the ideal one, and is therefore a measure of the degree to which the system fails to reproduce the transmitted signal. In his discussion, Wilson considered negative distortion areas to be an aid to resolution, indicating the desirability of overshoot following a transition.

All of these criteria are useful for the comparison of vertical and horizontal resolution, and for the comparison of the resolution of different systems.

In view of these criteria, the resolution is usually regarded as being directly proportional to the band-width, as shown in Figure 14.[14,15]

---

[12] A. V. Bedford and G. L. Fredendall, "Analysis, Synthesis, and Evaluation of the Transient Response of Television Apparatus," Proc. I.R.E., Volume IV, October, 1942.

[13] J. C. Wilson, "Television Transmission Equipment," Journal of the Television Society (London), Volume 1, p. 250.

[14] D. G. Fink, Principles of Television Engineering, (McGraw-Hill Book Co., Inc., New York, 1940), p. 501.

[15] R. E. Shelby, F. J. Somers, and L. R. Moffett, "Naval Airborne Television Reconnaissance System," RCA Review, Volume 7, September, 1946, p. 312.

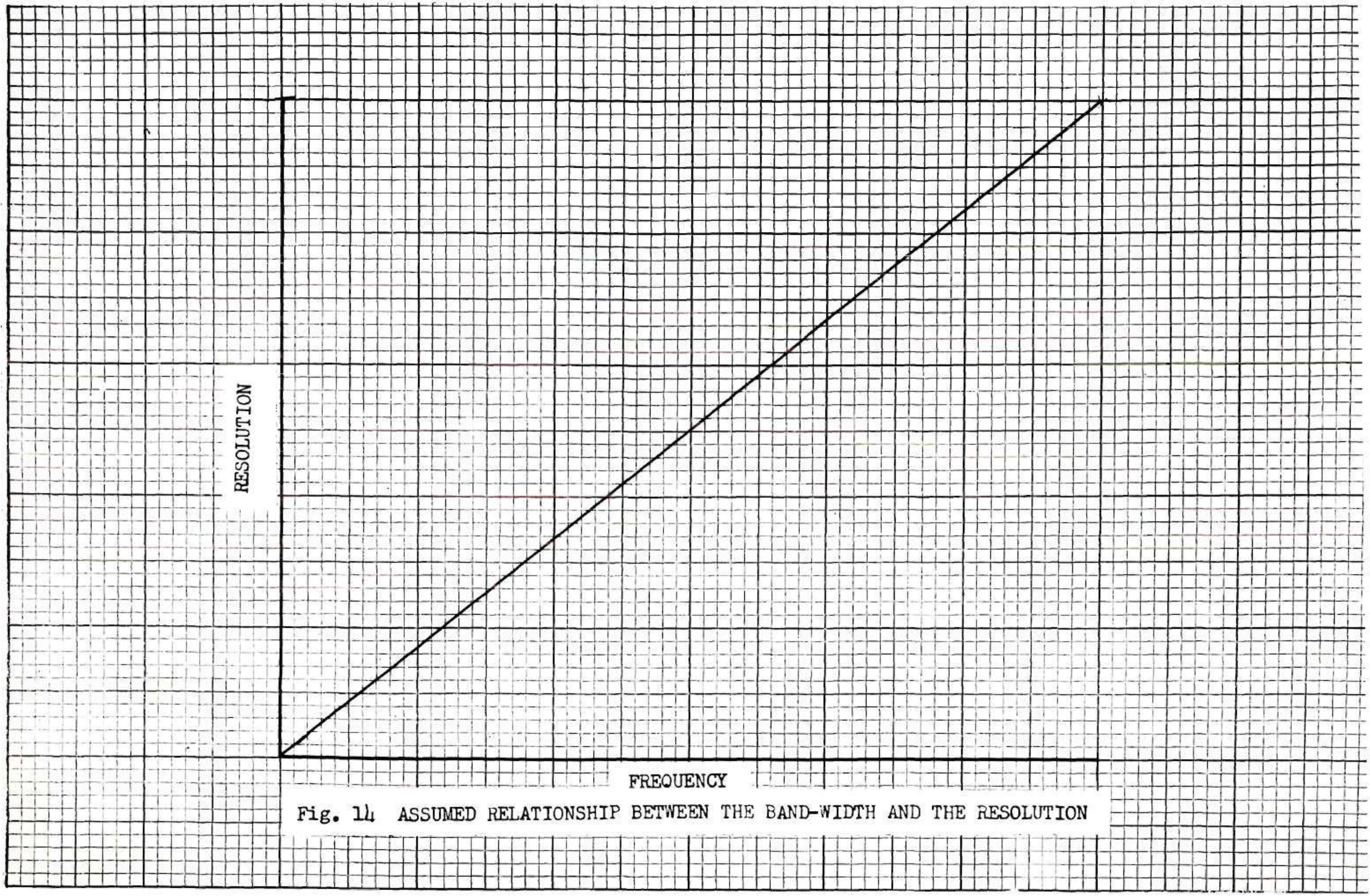


Fig. 14 ASSUMED RELATIONSHIP BETWEEN THE BAND-WIDTH AND THE RESOLUTION

Although this assumption is true within limits when the signal is transmitted by an ideal low-pass filter, it is not valid when a practical transmission system with gradual cut-off is considered, as will be shown in the following discussion.

Two narrow bars with narrow separation are shown in Figure 15a. The brightness needed so these bars will just be resolved by direct vision is shown in Figure 15c. Two wide bars with wide separation are shown in Figure 15b. The brightness needed so these bars will just be resolved by direct vision is shown in Figure 15d. This brightness is less than that needed in Figure 15c, because less contrast is needed to resolve wide bars with wide separation, as discussed under Case II.

Now let each pair of bars be transmitted over a television system which passes only the fundamental frequency of the video signal generated by that pair of bars. The brightness needed for threshold resolution of the television image of the narrow bars is shown in Figure 15e. Then, by comparison with Figures 15c and 15d it may logically be assumed that the brightness needed to just resolve the television image of the wide bars is similar to that given by Figure 15f.

However, the concept of a linear relationship between the resolution and the band-width is based upon the assumption that the same amplitude of video signal is needed for resolution regardless of the bar size and separation, as shown in Figure 15h. Obviously, this viewpoint is incompatible with the preceding discussion, since less contrast is needed to resolve bars with wide separation.

Fig. 15a NARROW BARS

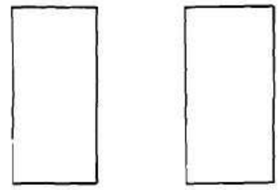


Fig. 15b WIDE BARS

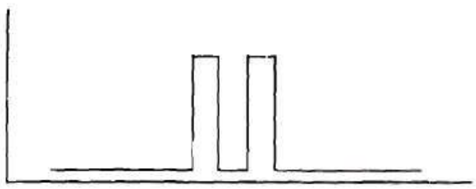


Fig. 15c

BRIGHTNESS REQUIRED TO RESOLVE NARROW BARS

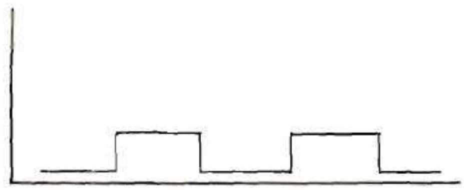


Fig. 15d

BRIGHTNESS REQUIRED TO RESOLVE WIDE BARS

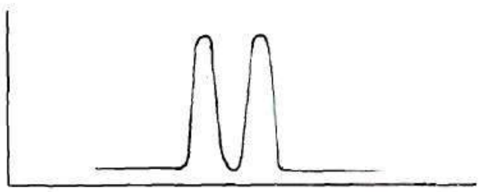


Fig. 15e BRIGHTNESS REQUIRED

TO RESOLVE NARROW BAR IMAGES

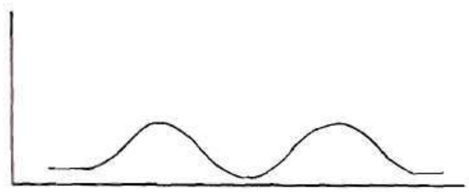


Fig. 15f BRIGHTNESS REQUIRED

TO RESOLVE WIDE BAR IMAGES

Fig. 15 CONTRAST REQUIRED

FOR

THRESHOLD RESOLUTION OF BARS

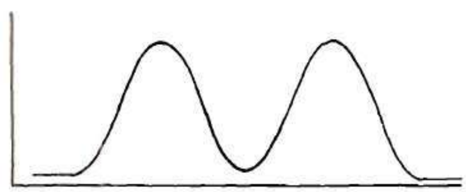


Fig. 15h BRIGHTNESS REQUIRED IF RESOLUTION

WERE DIRECTLY PROPORTIONAL TO BAND-WIDTH

EXPERIMENTAL APPROACH

The relationship between the resolution and the band-width was explored experimentally by the observation of resolution patterns by a number of observers. These television patterns were televised under the four band-width conditions shown in Figure 7. Two criteria have been suggested for the measurement of threshold vision.[1] The first, "recognition of presence," is concerned with the recognition of the presence of an object in the field of vision. The second, "recognition of detail," implies recognition of some critical detail, such as the shape of an object or the separation of two adjacent lines. The criterion selected for this research is threshold recognition of detail.

Proposed Figure of Merit

In order to correct for variations of the visual acuity of the different observers, it was planned to measure the minimum visual angle (A_d) subtended by the critical detail in a test chart which could be discerned by direct vision, and the minimum visual angle (A_t) subtended by the critical detail which could be discerned by observation of a television image viewed from a fixed distance. The ratio $M = A_d/A_t$ would give a "Figure of Merit" (M) for the television system which, it was hoped, would be independent of the visual acuity of the observer.

After preliminary observations to determine the feasibility of this figure of merit, it became apparent that the resolution of the television system was not sufficiently great enough for the visual acuity

[1]M. Luckiesh and F. K. Moss, *Op. Cit.*, p. 142.

of the observer to be a limiting factor in the resolution of detail. The main consideration for resolution, as discussed under Case III, is the ability of the observer to separate areas of different brightness levels. This ability is apparently not related to the problem of visual acuity. For this reason the figure of merit was not employed. However, it may be useful in the evaluation of high-resolution television systems, and it has possible applications in other fields.

Test Patterns

Words and sentences were not used for test pattern material because they might be anticipated or memorized unconsciously by the observer. Random letters were not employed because it is difficult to determine the resolution required to read each letter, as some are more easily read than others.

An initial test pattern was obtained by placing the letter "T" in various positions as shown in Figure 16. This "T-Chart" was reproduced photographically in ten graduated sizes and employed in preliminary tests.[2] The results of these tests disclosed that the "T's" could be resolved in certain positions even when the horizontal resolution was very poor, due to the information contributed by the vertical resolution. Since this caused misleading results, the use of these charts was discontinued.

The standard test chart[3,4] shown in Figure 17 was found useful

---

[2]The test consisted of the identification of the position of each "T", that is, the direction in which the staff of each "T" was pointing.

[3]A. V. Bedford, "Figure of Merit for Television Performance," RCA Review, Volume III, July, 1938, p. 36.

[4]Standards on Television, (The Institute of Radio Engineers, New York, 1948), p. 24.

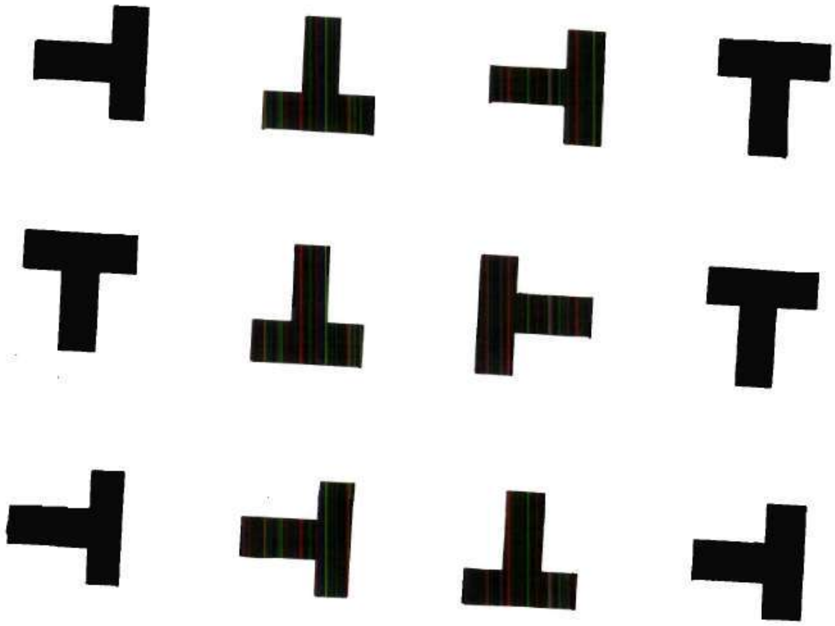


Fig. 16 T-CHART

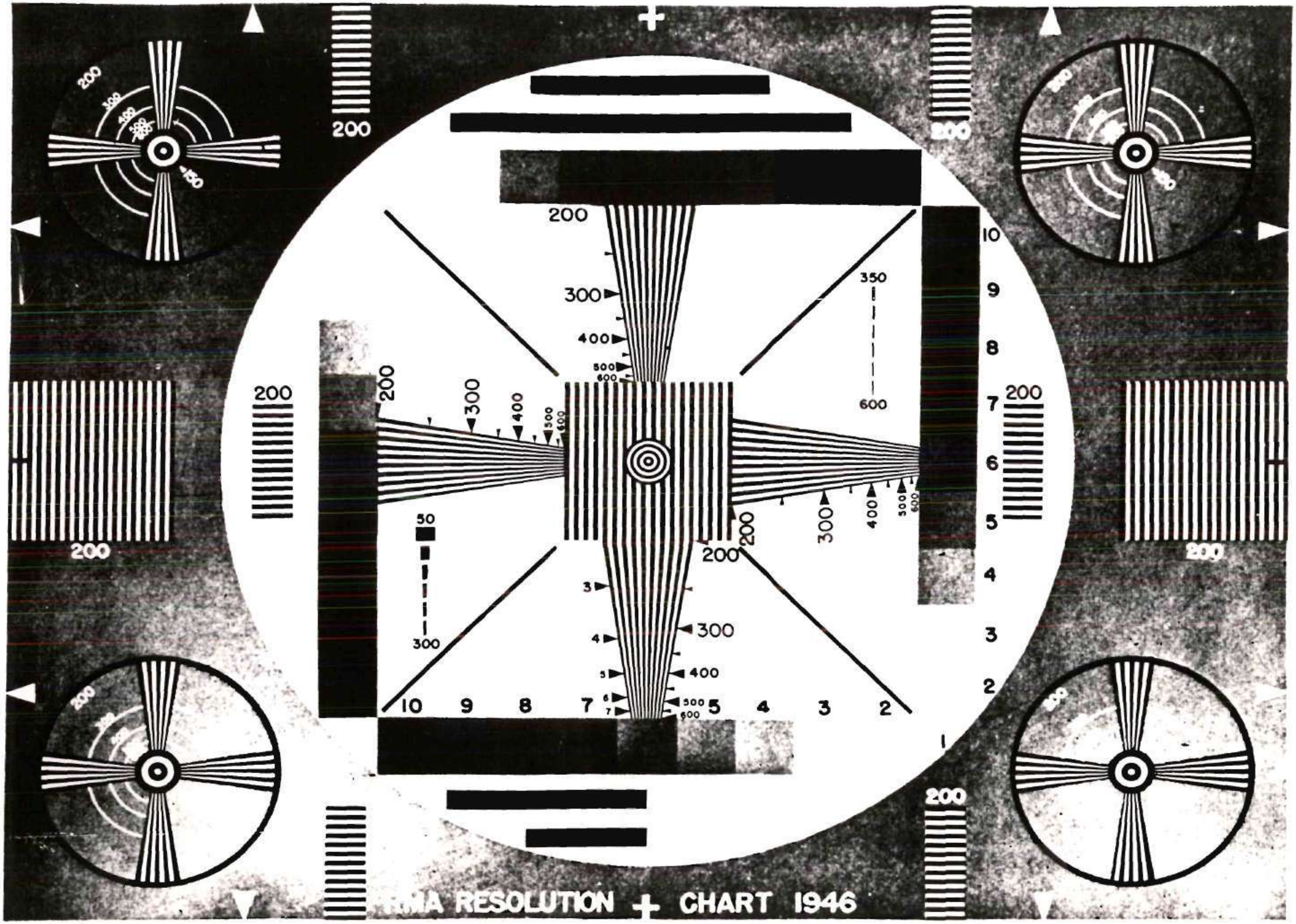


Fig. 17 STANDARD RMA TEST CHART

for adjustment purposes, but only rough estimates of the resolution could be made using this pattern. As an adaptation of the wedge chart, the pattern shown in Figure 18a was constructed. The number of bars of the television chart that can be counted gives a direct indication of the resolution of the television system. Two additional charts covering the lower values of resolution were obtained by enlarging this chart to twice its size and four times its size. These charts, shown in Figures 18a, 18b, and 18c will be referred to as Bar Chart #1, Bar Chart #2, and Bar Chart #3 respectively. These three charts permit resolution measurements from 50 lines to 380 lines. Resolution values corresponding to bar chart readings, and the design information for the charts, are given in Appendix VI.

Psychological Considerations

Several psychological considerations will be considered briefly. An adaptation period was necessary preceding the tests to permit the observer's eyes to become adapted to the reduced level of illumination, since the tests were held in a darkened room. Observer fatigue made the readings inconsistent when the viewing time was excessive, since the tests involved close scrutiny. The viewing history of the observer had a bearing on the readings, those having oscilloscope or radar experience making better scores than untrained observers. Since the readings were also affected by the degree of familiarity of the observer with the test material, the patterns were presented for examination before the actual test.

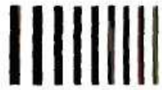


Fig. 18(a) BAR CHART 3

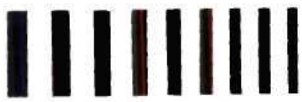


Fig. 18(b) BAR CHART 2

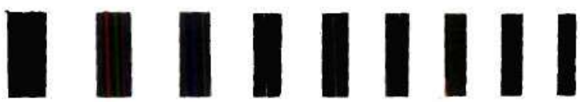


Fig. 18(c) BAR CHART 1

Test Procedure

The observer was seated before the monitor in a darkened room and was acquainted with the test patterns and with the testing method. The bar charts were then presented in a random order. Each chart was employed twice, making a total of six presentations for each band-width condition. There was no time limit for the observations, and the observer was permitted to view the screen from any desired distance.

EXPERIMENTAL RESULTS OF BAR CHART OBSERVATIONS

A thorough statistical study of the resolution of the bar charts over the television system was beyond the scope of this thesis, and reliable experimental conclusions cannot be presented without such a study.[1] For this reason, data is presented here only for the purpose of illustrating the order of results that might be obtained by a more critical study of the problem under more carefully controlled test conditions.

A large portion of the experimental data obtained in these tests was rejected due to extreme variations in readings. These variations were caused by one or more of the following factors.

1. The adjustment of the television equipment was very critical, and the apparatus was unstable in the presence of mechanical vibration or shock. Therefore the performance of the system sometimes changed considerably during the course of a test. For this reason, the apparatus was adjusted for optimum performance prior to each test, and the adjustment was checked at the conclusion of each test. Whenever the performance had deteriorated noticeably, the data obtained by that run was discarded.

2. Due to the limited scope of this experimental work, the observers were not properly "seasoned" in the observation of the television image, as they must be if consistent readings are to be obtained. As a result, there was a wide variation in the readings by different

---

[1]The experimental procedure which should be followed is suggested by the following reports of similar investigations: Baldwin, Op. Cit., and Blackwell, Loc. Cit.

observers.

3. Some of the readings involved the resolution of bars under conditions of very low contrast. In such instances, the readings varied with the degree of observer fatigue and with the amount of effort and imagination expended by the observer in the critical examination of the television image.

The following table presents the average results of six tests which were selected from eleven tests on the basis of being fairly consistent and representative of the capabilities of the television system. Each entry in the table indicates the average number of bars on a given bar chart that were resolved under a given band-width. From these average bar-chart readings, the resolutions corresponding to the four band-widths have been computed.[2]

Table II

Average Number of Bars Resolved in Six Selected Tests

Bar Chart #	1	2	3	Resolution
Network				
Net A	10	10	3.58	252
Net B	10	9.28	1.42	208
Net C	10	8.24	0.25	172
Net D	9.76	4.33	0.0	133

[2]The original data from which this table was taken is presented in Appendix VII.

In order to compare the resolution with the band-width, some nominal measure of the band-width is needed for each of the four conditions. After examination of the amplitude characteristic curves given in Figure 7, the 80% response was arbitrarily selected to indicate the channel width. (Any reasonable value below 80% would give substantially the same results. However, a higher value of percentage response would not be representative of the band-width under Net A.) These band-widths are shown in Table III with their corresponding resolution measurements.

Table III

Resolution as a Function of the Band-Width From Six Selected Tests

Network:	Band-Width	Resolution
Net A	2.8 mc.	252
Net B	770 kc.	208
Net C	340 kc.	172
Net D	100 kc.	133

There are several reasons why this data does not accurately express the resolution as a function of the band-width.

1. The shape of the characteristic curves are not identical for the four band-width conditions. Therefore the frequencies chosen to represent the channel width do not have the same significance in all four cases. For example, the characteristic curve for Condition A cuts off more sharply than the curve for Condition D. Thus 2.8 mc is a less conservative measure of the band-width of Condition A than 100 kc is of

Condition D. (The dip on the curve of Condition A is of no importance because the frequency corresponding to the threshold resolution is above 2.6 mc.)

2. Random noise, aperture distortion, and especially the stray signal mentioned previously had a detrimental effect on the high-resolution readings. For this reason, the resolution under Condition A is probably lower than it should be.

3. Since the scope of this phase of the thesis was limited, there was not a sufficient number of observations taken to insure reliable results. In other words, the probable error of observation is high.

The experimental data contained in Table III is plotted on linear coordinate paper in Figure 19. The commonly assumed linear relationship between the band-width and the resolution is shown for comparison. It may be seen that the resolution corresponding to the narrow band-widths greatly exceeds the expected resolution.

Discussion of Curve

The shape of the curve must be interpreted in the light of the qualifications placed upon the experimental data from which it was obtained. In view of the first two limitations discussed above, the resolution reading under Condition A should be increased, and that under Condition B should be increased by a smaller amount. After these modifications are considered, the shape of the curve must be attributed to the manner in which the eye and the sensory system interprets the information presented on the screen. It is now seen experimentally that less contrast is needed for low resolution than is needed for high resolution,

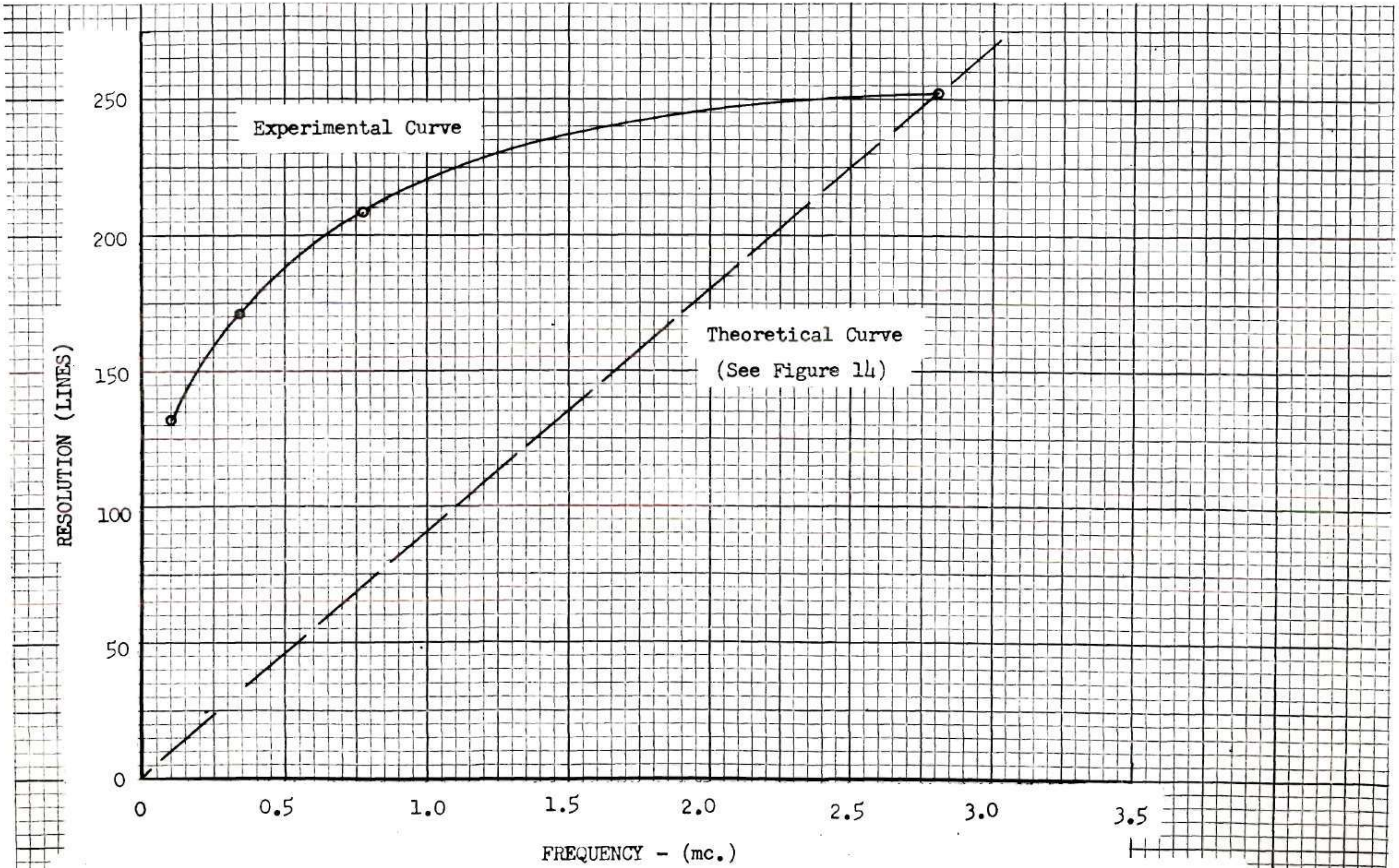


Fig. 19 RELATIONSHIP BETWEEN THE BAND-WIDTH AND RESOLUTION AS DETERMINED BY SIX SELECTED TESTS

as was discussed in the section on Resolution.

It is not to be assumed that the value of information transmitted under threshold conditions is the same for all band-widths. The contrast was very poor for the low-resolution readings and the certainty of observation was less than for the high-resolution readings.

It is interesting to note that the experimental data given in Table III is practically a straight line when plotted on semi-logarithmic coordinate paper as shown in Figure 20.

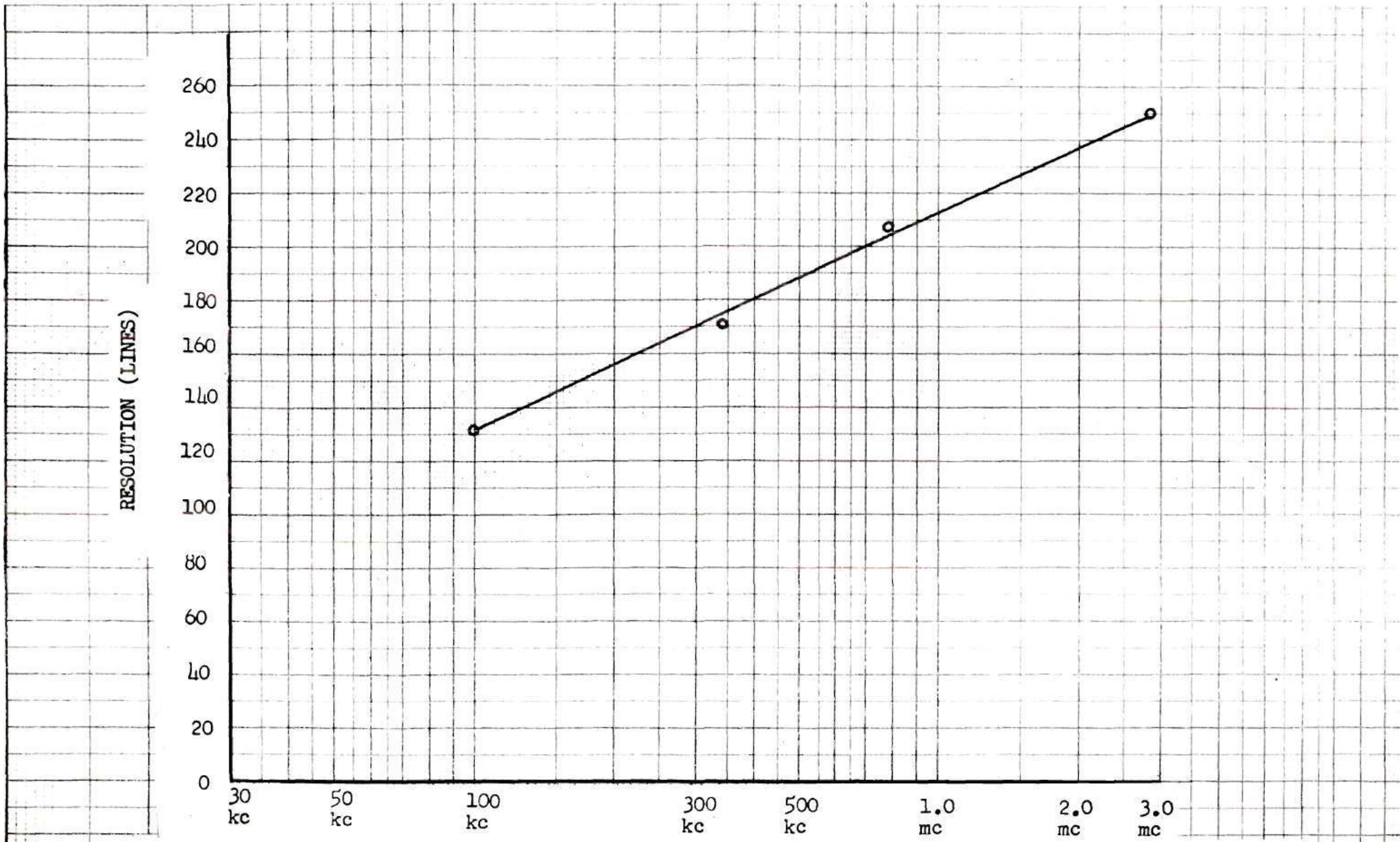


Fig. 20 RELATIONSHIP BETWEEN THE BAND-WIDTH AND RESOLUTION AS DETERMINED BY SIX SELECTED TESTS

(See Figure 19)

PHOTOGRAPHIC RESULTS

The effect of the channel width upon the resolution and the picture quality is illustrated by photographs of a number of subjects transmitted under the four band-width conditions. All photographs of television images were made with the Du Mont Oscillographic Camera.

Figure 21 - Bar Charts

The bar charts presented in Figure 18 are shown under the four band-width conditions. It will be noted that the high resolution readings are fairly consistent with the data given in Table II, but under Conditions C and D the resolution is apparently poorer than that recorded in the observation tests. This may be ascribed to the loss of contrast in the photographic processes.

Figure 22 - Large Bar Chart

An enlargement of the bar chart was televised to illustrate the degree of distortion present under Conditions C and D. Condition A permits fairly sharp transition edges, while under Condition B they are blurred. Under Condition C the video signal apparently does not achieve its full value of black for the narrow bars, and under Condition D maximum black is not reached for any of the bars, but all the bars are still easily resolved.

Figure 23 - Bars

This series again illustrates the reproduction of vertical bars of different widths under different band-width conditions.

Figures 24 and 25 - Eye Charts

Two charts employed to test visual acuity were reduced and televised.[1] These charts are based upon the Snellen letters.

Figure 26 - Similar Letters

This chart was constructed to determine the probability of confusion between similar letters. It is seen that the letters "O" and "D" are among those most likely to be confused. Special type design would result in greater legibility.

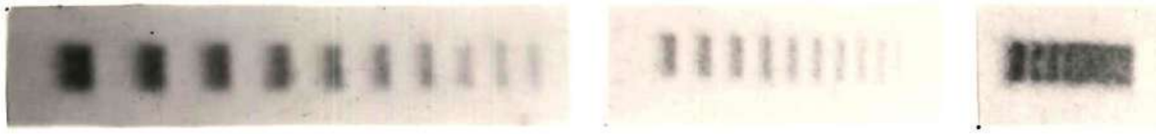
Figures 27 through 30 - Pictorial Subjects

Several subjects of a more general nature are shown to demonstrate the effect of the band-width on the type of subject matter customarily transmitted. It will be noted that the large mismatch between the vertical and horizontal resolutions is not as objectionable as might be expected. This observation is in agreement with established experimental results.[2]

---

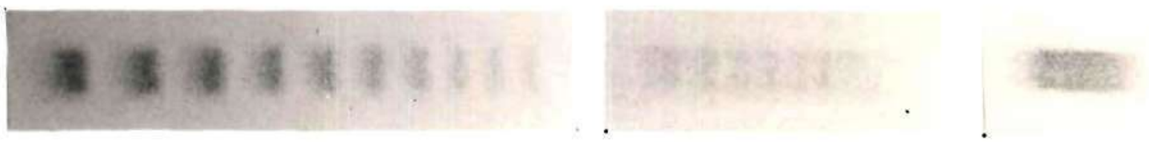
[1]Luckiesh, Op. Cit., p. 64.

[2]Baldwin, Op. Cit.



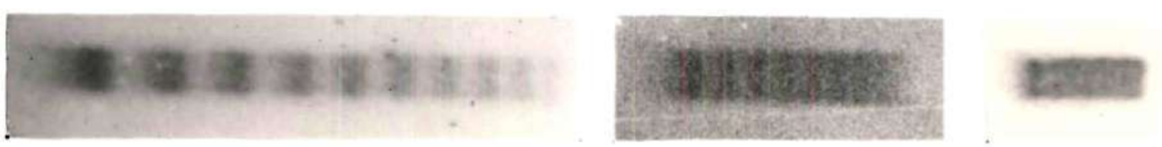
BAR CHART 1 BAR CHART 2 BAR CHART 3

CONDITION A



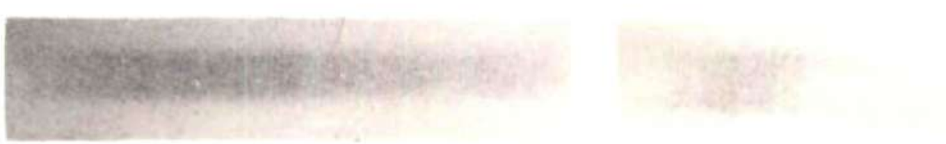
BAR CHART 1 BAR CHART 2 BAR CHART 3

CONDITION B



BAR CHART 1 BAR CHART 2 BAR CHART 3

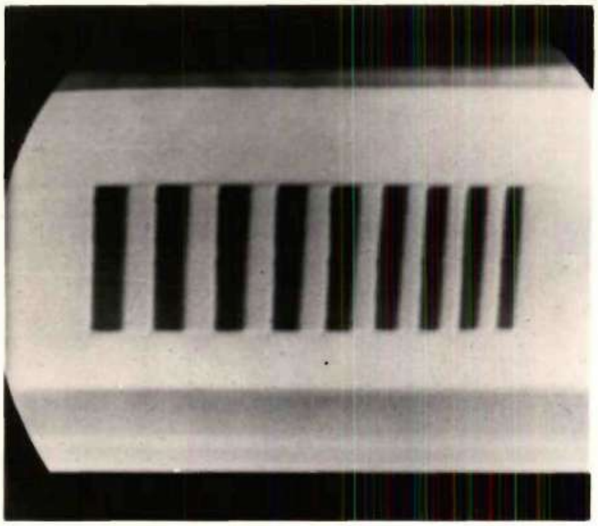
CONDITION C



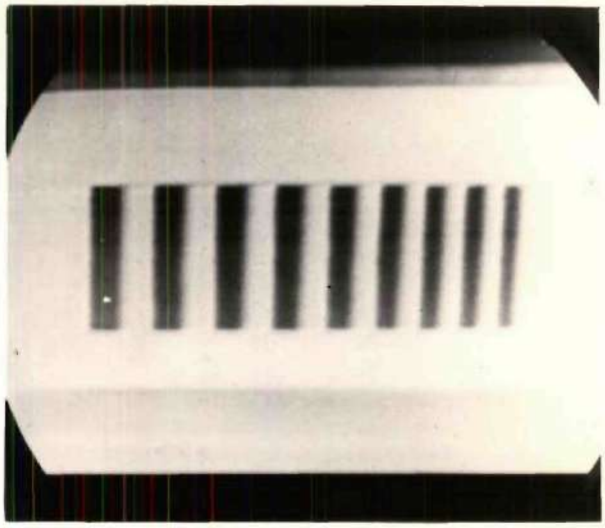
BAR CHART 1 BAR CHART 2

CONDITION D

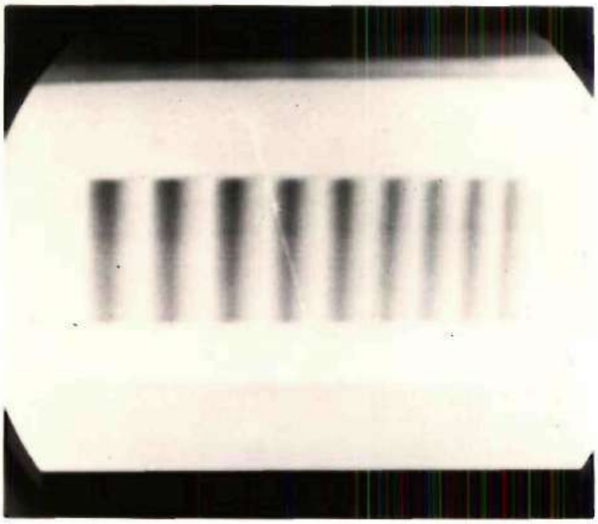
FIG. 21 BAR CHARTS



CONDITION A



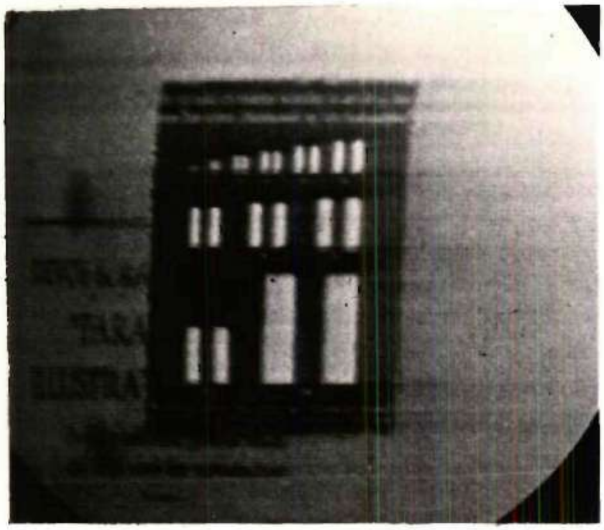
CONDITION B



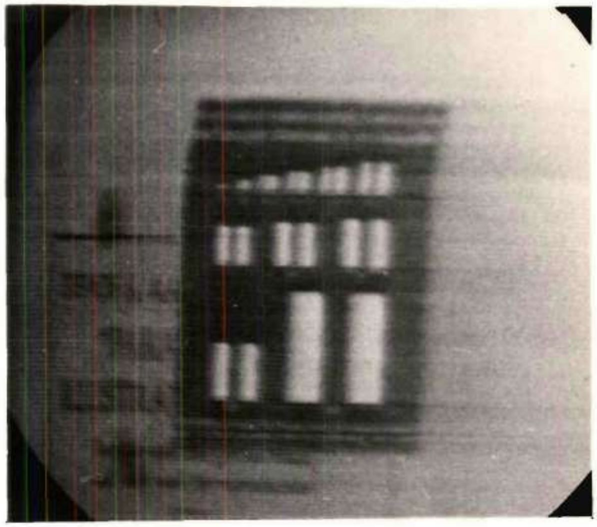
CONDITION C

CONDITION D

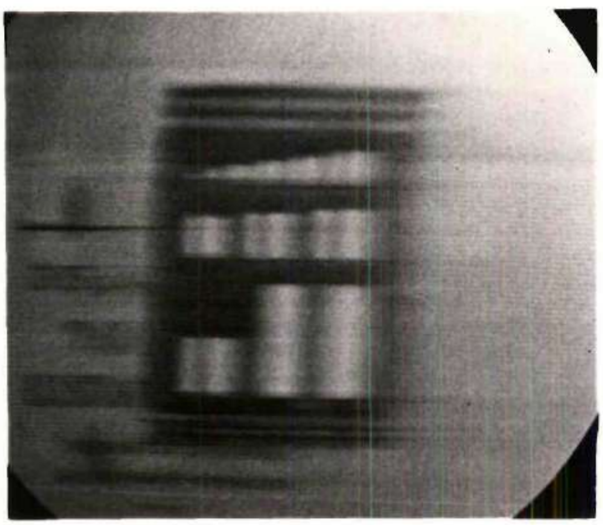
FIG. 22 ENLARGED BAR CHART



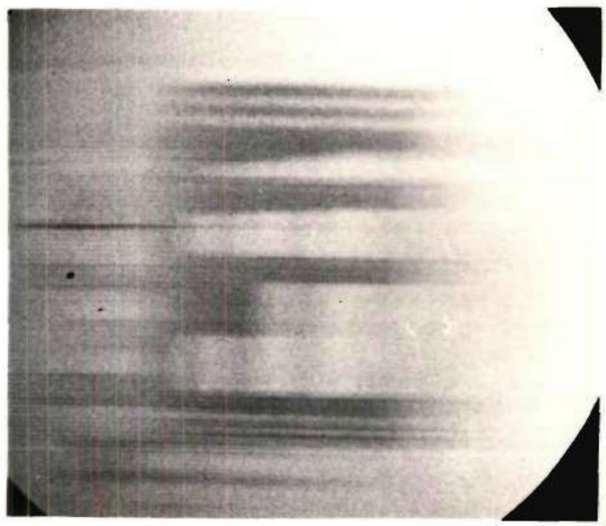
CONDITION A



CONDITION B



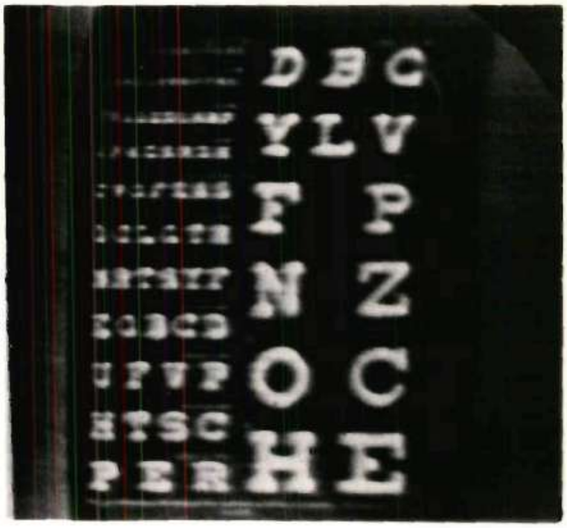
CONDITION C



CONDITION D

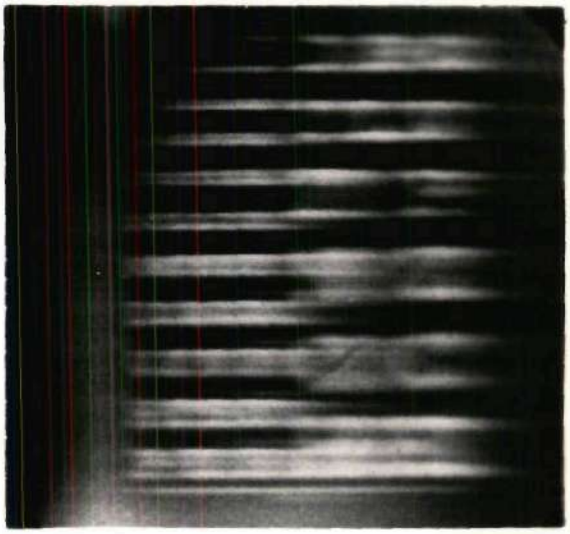
FIG. 23 BARS

CONDITION A



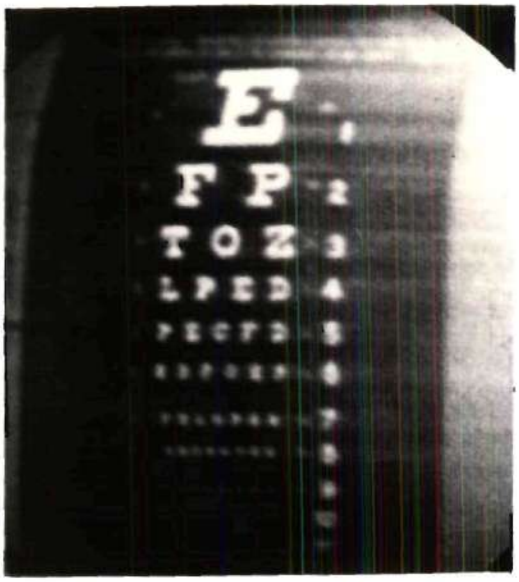
CONDITION B

CONDITION C



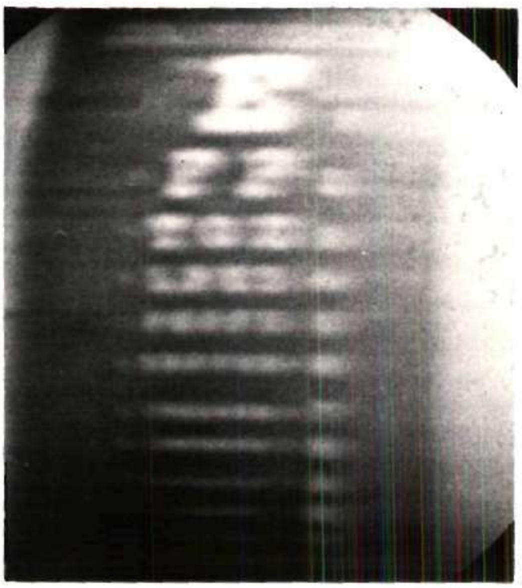
CONDITION D

FIG. 24 SNELLEN EYE CHART

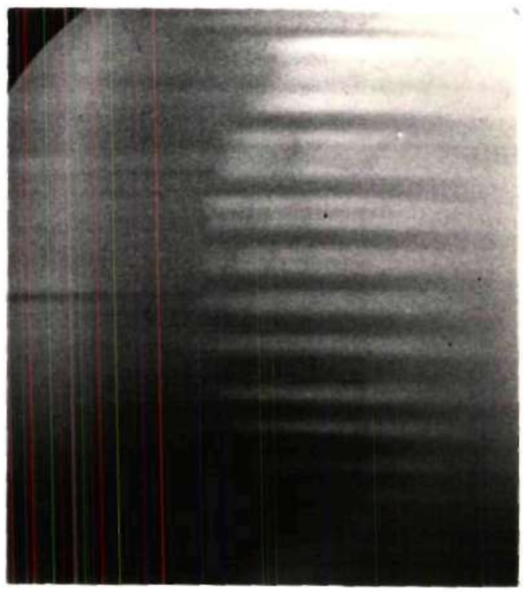


CONDITION A

CONDITION B



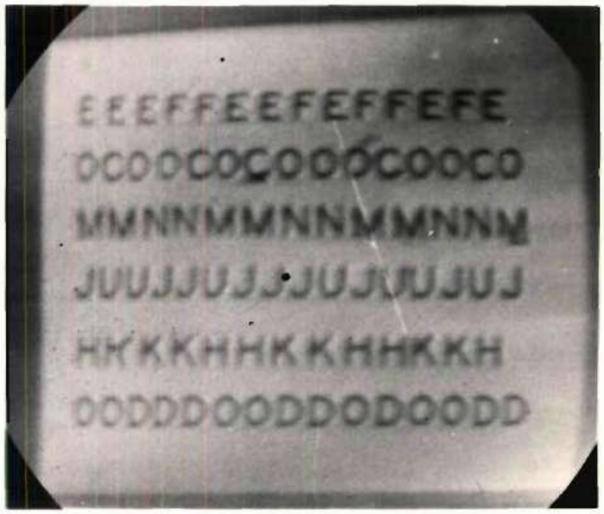
CONDITION C



CONDITION D

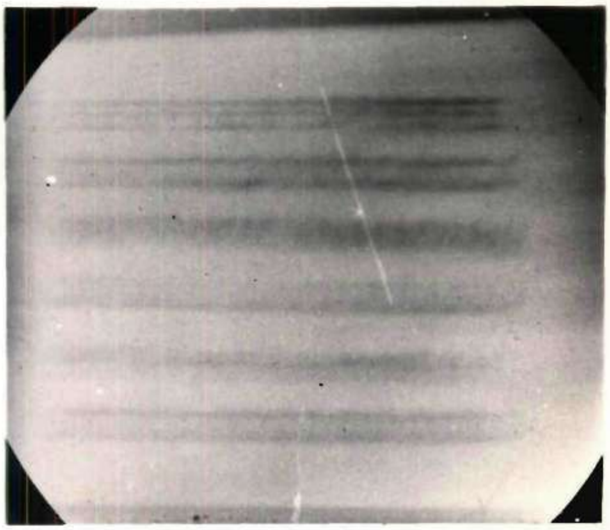
FIG. 25 SNELLEN EYE CHART

CONDITION A



CONDITION B

CONDITION C



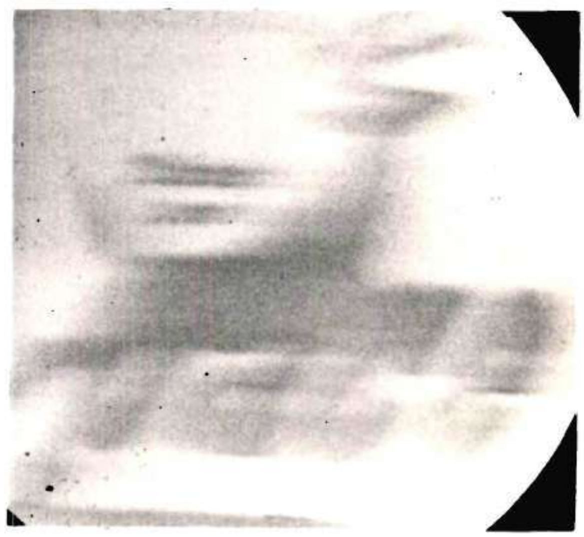
CONDITION D

FIG. 26 SIMILAR LETTERS

CONDITION A

CONDITION B

CONDITION C



CONDITION D

FIG. 27 PICTORIAL SUBJECT

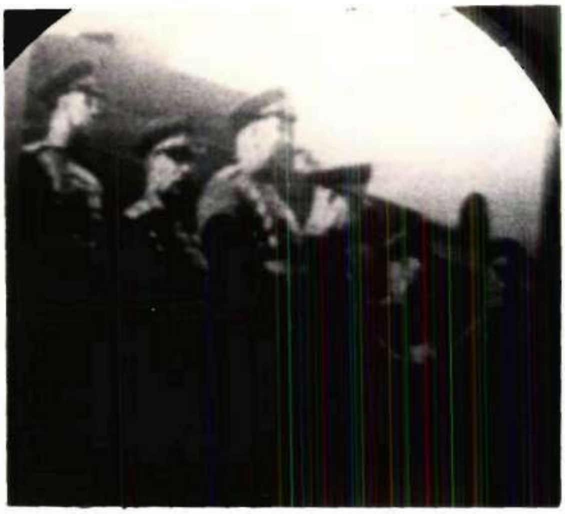
CONDITION A

CONDITION B

CONDITION C

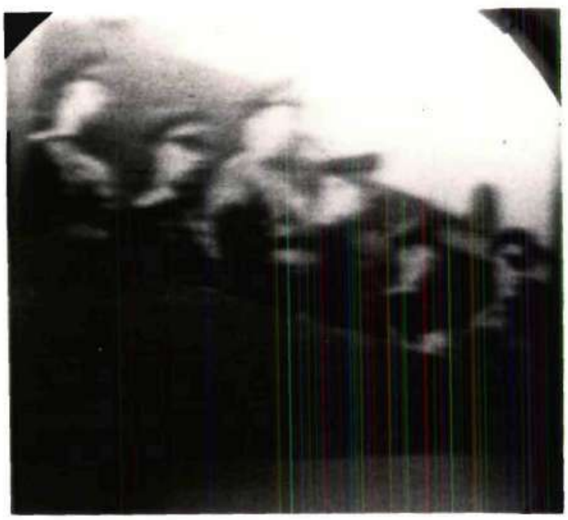
CONDITION D

FIG. 28 PICTORIAL SUBJECT



CONDITION A

CONDITION B



CONDITION C

CONDITION D

FIG. 29 PICTORIAL SUBJECT

CONDITION A

CONDITION B

CONDITION C

FIG. 30 PICTORIAL SUBJECT

SUMMARY AND CONCLUSIONS

This thesis is concerned with the factors which affect the horizontal resolution of a television system, and primarily with the effect of the band-width upon the horizontal resolution. The response of the scanning spot to a step of brightness is shown, and the imperfect reproduction of the video system is discussed. Resolution is considered with regard to the manner in which the sensory system interprets the information which is presented to the eye. Experimental research relating the resolution to the contrast is referred to, and these results are discussed with respect to the resolution of a television image. It is seen from this discussion that the resolution of a television system is not directly proportional to the band-width due to the fact that less contrast is needed to resolve large detail than is needed to resolve minute detail. The work of several investigators which dealt with experimental determination of resolution is summarized. Several proposed theoretical criteria for resolution as a function of the channel width are presented.

The relationship between the band-width and the resolution was investigated experimentally employing a television system. Coupling networks were designed and constructed which give four distinct band-width conditions of approximately the same shape of amplitude characteristic curves, but with different cut-off frequencies. The use of these compensated networks is well adapted to the study and the demonstration of the effect of the band-width upon the resolution. A set of test patterns was designed which gives a direct indication of the horizontal resolution of the television system. These test patterns were presented to a number of observers over the television system under the four band-width conditions. The experimental results indicate that a higher resolution is obtainable with a narrow band-width than would be expected if the resolution is directly proportional to the band-width. This result substantiates the discussion concerning the sensory response to a television image.

In the course of this research, several interesting problems were encountered. They are briefly presented here.

A novel means of image reconstitution was observed and a preliminary investigation was conducted. The results are presented in Appendix VIII.

The use of a scanning spot in the kinescope with an elliptical cross-section rather than the conventional circular cross-section was considered. Possible advantages include the reduction in the visibility of the scanning lines without a decrease in the horizontal resolution, and a reduction of spurious patterns.

BIBLIOGRAPHY

Bachman, C. H., "Image Contrast in Television," General Electric Review, Vol. 48, September, 1945.

Baldwin, M. W., Jr., "The Subjective Sharpness of Simulated Television Images," Proc. IRE, Vol. 28, October, 1940.

Bedford, A. V., "Figure of Merit for Television Performance," RCA Review, Vol. 3, July, 1938.

Bedford, A. V. and G. L. Fredendall, "Transient Response of Multistage Video-Frequency Amplifiers," Proc. IRE, Vol. 27, April, 1939.

Bedford, A. V. and G. L. Fredendall, "Analysis, Synthesis, and Evaluation of the Transient Response of Television Apparatus," Proc. IRE, Vol. 30, October, 1942.

Blackwell, H. R., "Contrast Thresholds of the Human Eye," Journal of the Optical Society of America, Vol. 36, November, 1946.

Engstrom, E. W., "A Study of Television Image Characteristics," Proc. IRE, Vol. 21, December, 1933.

Epstein, D. W. and L. Pensak, "Improved Cathode-Ray Tubes with Metal-Backed Luminescent Screens," RCA Review, March, 1946.

Fink, D. G., Radar Engineering, New York: McGraw-Hill Book Company, Inc., 1947.

Freedman, R. L. and J. D. Schantz, "Video Amplifier Design," Electronics, Vol. 10, August, 1937.

Fry, G. A., "The Relation of the Configuration of a Brightness Contrast Border to its Visibility," Journal of the Optical Society of America, No. 37, 1947.

Goldmark, P. C., "Brightness and Contrast in Television," Electrical Engineering, Vol. 68, March, 1949.

Guilleman, E. A., Communications Networks, Vol. II, New York: John Wiley and Sons, Inc., 1935.

Harries, J. H. O., "A Quantitative Analysis of Television," Television, (London), Vol. 12.

Herold, E. W., "High Frequency Correction in Resistance-Coupled Amplifiers," Communications, August, 1938.

Hodgman, C. D., Handbook of Chemistry and Physics, Cleveland: Chemical Rubber Publishing Co., 1947.

Kell, R. D., A. V. Bedford, and G. L. Fredendall, "A Determination of Optimum Number of Lines in a Television System," RCA Review, July, 1940.

Langmuir, D. B., "Theoretical Limitations of Cathode-Ray Tubes," Proc. IRE, Vol. 25, August, 1937.

Law, R. R., "Contrast in Kinescopes," Proc. IRE, Vol. 27, August, 1939.

Luckiesh, M., and F. K. Moss, The Science of Seeing, New York: Van Nostrand Co., Inc., 1937.

Mac Lean, W. R., "Ultimate Band-Widths in High-Gain Multi-Stage Video Amplifiers," Proc. IRE, Vol. 32, January, 1944.

Marshall, C. J. and L. Katz, "Television Equipment for Guided Missiles," Proc. IRE, Vol. 34, June, 1946.

Mertz, P. and F. Gray, "A Theory of Scanning and its Relation to the Characteristics of the Transmitted Signal in Telephotography and Television," Bell System Technical Journal, Vol. 13, September, 1934.

Rayleigh, Lord J. W., "Investigations in Optics," Philosophical Magazine, 5th Series, Vol. 8, October, 1879.

Schade, O. H., "Electro-Optical Characteristics of Television Systems," RCA Review, Part I, "Characteristics of Vision and Visual Systems," Vol. 9, March, 1948; Part II, "Electro-Optical Specifications for Television Systems," Vol. 9, June, 1948; Part III, "Electro-Optical Characteristics of Camera Systems," Vol. 9, September, 1948; Part IV, "Correlation and Evaluation of Electro-Optical Characteristics of Imaging Systems," Vol. 9, December, 1948.

Seal, P. M., "Square-Wave Analysis of Compensated Amplifiers," Proc. IRE, Vol. 37, January, 1949.

Seeley, S. W. and G. N. Kimball, "Analysis and Design of Video Amplifiers," RCA Review, Vol. 2, October, 1937.

Seeley, S. W. and G. N. Kimball, "Analysis and Design of Video Amplifiers," Part II, RCA Review, January, 1939.

Shelby, R. E., F. J. Somers, and L. R. Moffett, "Naval Airborne Television Reconnaissance System," RCA Review, Vol. 7, September, 1946.

Trainer, M.A. and W. J. Poch, "Television Equipment for Guided Missiles," Proc. IRE, Vol. 34, July, 1946.

Wheeler, H. A. and A. V. Loughren, "The Fine Structure of Television Images," Proc. IRE, Vol. 26, May, 1938.

Wilson, J. C., "Channel Width and Resolving Power in Television Systems," Journal of the Television Society (London), Vol. 2, July, 1938.

Wilson, J. C., "Television Transmitting Equipment," Journal of the Television Society (London), Vol. 1.

Wilson, J. C., Television Engineering, London: Pitman and Sons, Ltd., 1937.

Zworykin, V. K. and G. A. Morton, Television, New York: John Wiley and Sons, 1940.

Note: Articles concerning television written by authors associated with RCA have been collected in the following four volumes:

Television, Vol. 1, New York: RCA Institutes Technical Press, July, 1936.

Television, Vol. II, New York: RCA Institutes Technical Press, October, 1937.

Television (1938-1941), Vol. III, Princeton: Radio Corporation of America, December, 1946.

Television (1942-1946), Vol. IV, Princeton: Radio Corporation of America, January, 1947.

A bibliography to articles concerning television articles written by authors associated with RCA prior to 1947 is contained in Television, Vol. IV.

APPENDIX I

COMPONENT VALUES FOR THE FOUR COMPENSATED COUPLING NETWORKS

A summary of the design parameters is given below.

$K = 1.41$ (arbitrarily chosen)

$R = 1000$ ohms (arbitrarily chosen)

$C_s = 40$ mmfd. (measured)

The following equations were used to find the component values.

$$C = K/(2\pi R f_o) \qquad (3)$$

$$L = (R^2/K^2)C \qquad (4)$$

$$C_a = C - C_s \qquad (5)$$

Using the above information, the coupling networks were designed about four arbitrarily chosen frequencies, as shown in Table I.

Table I

Component Values for the Four Compensated Coupling Networks

Net	f_o	C	L	C_a
A	1500 kc	106 mmfd.	53 uh.	66 mmfd.
B	500 kc	320 mmfd.	159 uh.	280 mmfd.
C	200 kc	800 mmfd.	398 uh.	760 mmfd.
D	75 kc	2130 mmfd.	1065 uh.	1990 mmfd.

When measuring the inductance, cognizance must be taken of the stray coil capacitance which results in an increase in the apparent inductance as the frequency increases, below the natural resonant frequency of the coil. By using low-capacitance pi-wound coils, the capacitance was kept low enough so that the inductance remained fairly constant throughout its useful range. Each inductance was measured near the design frequency for its network, as only in this region does the inductance have an appreciable effect on the coupling circuit.

DATA FOR CHARACTERISTIC CURVES

FOR THE FOUR BAND-WIDTH CONDITIONS

APPENDIX II

Part A.: Amplitude characteristic data for a single stage (the modified stage) under the four band-width conditions.

1. Stage under Condition A (coupled with Net A).

Frequency	Input (volts)	Output (volts)	Relative Amplitude
10 kc	1.0	2.73	1.0
100 kc	1.0	2.62	0.96
300 kc	1.0	2.58	0.945
500 kc	1.0	2.6	0.953
700 kc	1.0	2.62	0.96
1.0 mc	1.0	2.62	0.96
1.5 mc	1.0	2.58	0.945
2.0 mc	1.0	2.45	0.898
2.5 mc	1.0	2.25	0.825
3.0 mc	1.0	1.98	0.725
3.5 mc	1.0	1.7	0.622
4.0 mc	1.0	1.42	0.52
4.5 mc	1.0	1.22	0.446
5.0 mc	1.0	1.08	0.396

APPENDIX II (CONTINUED)

2. Stage under Condition B (coupled with Net B).

Frequency	Input (volts)	Output (volts)	Relative Amplitude
10 kc	1.0	2.78	1.0
100 kc	1.0	2.6	0.935
300 kc	1.0	2.6	0.935
500 kc	1.0	2.52	0.906
700 kc	1.0	2.25	0.81
1.0 mc	1.0	1.72	0.618
1.5 mc	1.0	1.08	0.388
2.0 mc	1.0	0.75	0.27
2.5 mc	1.0	0.575	0.207
3.0 mc	1.0	0.485	0.174
3.5 mc	1.0	0.405	0.145
4.0 mc	1.0	0.35	0.125
4.5 mc	1.0	0.30	0.11
5.0 mc	1.0	0.27	0.1

APPENDIX II (CONTINUED)

3. Stage under Condition C (coupled with Net C).

Frequency	Input (volts)	Output (volts)	Relative Amplitude
10 kc	1.0	2.73	1.0
100 kc	1.0	2.7	0.99
300 kc	1.0	2.4	0.88
500 kc	1.0	1.6	0.586
700 kc	1.0	1.08	0.396
1.0 mc	1.0	0.68	0.25
1.5 mc	1.0	0.43	0.157
2.0 mc	1.0	0.31	0.113
2.5 mc	1.0	0.25	0.092
3.0 mc	1.0	0.208	0.076
3.5 mc	1.0	0.18	0.066
4.0 mc	1.0	0.153	0.056
4.5 mc	1.0	0.135	0.049
5.0 mc	1.0	0.12	0.044

APPENDIX II (CONTINUED)

4. Stage under Condition D (coupled with Net D).

Frequency	Input (volts)	Output (volts)	Relative Amplitude
10 kc	1.0	2.74	1.0
100 kc	1.0	2.25	0.82
300 kc	1.0	0.685	0.25
500 kc	1.0	0.301	0.11
700 kc	1.0	0.219	0.08
1.0 mc	1.0	0.178	0.065
1.5 mc	1.0	0.137	0.05
2.0 mc	1.0	0.11	0.04

APPENDIX II (CONTINUED)

Part B: Amplitude characteristic data for the over-all system under the four band-width conditions.

1. System under Condition A.

Frequency	Input (millivolts)	Output (volts)	Relative Amplitude
10 kc	1.3	.44	1.0
100 kc	1.23	.402	.975
300 kc	1.15	.37	.951
500 kc	1.12	.35	.922
700 kc	1.12	.33	.868
1.0 mc	1.11	.313	.834
1.5 mc	1.08	.293	.804
2.0 mc	1.06	.304	.845
2.5 mc	1.07	.309	.854
3.0 mc	1.105	.222	.566
3.5 mc	1.1	.161	.432
4.0 mc	1.04	.105	.298
4.5 mc	1.07	.053	.146
5.0 mc	1.00	.017	.05

APPENDIX II (CONTINUED)

2. System under Condition B.

Frequency	Input (millivolts)	Output (volts)	Relative Amplitude
10 kc	1.3	.452	1.0
100 kc	1.22	.410	.965
300 kc	1.13	.382	.97
500 kc	1.13	.368	.936
700 kc	1.11	.330	.855
1.0 mc	1.10	.247	.643
1.5 mc	1.06	.15	.406
2.0 mc	1.04	.108	.299
2.5 mc	1.08	.0815	.217
3.0 mc	1.11	.043	.111
3.5 mc	1.10	.0228	.059
4.0 mc	1.02	.014	

APPENDIX II (CONTINUED)

3. System under Condition C.

Frequency	Input (millivolts)	Output (volts)	Relative Amplitude
10 kc	1.3	.442	1.0
100 kc	1.22	.408	.98
300 kc	1.13	.332	.865
500 kc	1.12	.20	.526
700 kc	1.11	.13	.344
1.0 mc	1.1	.078	.208
1.5 mc	1.07	.0474	.13
2.0 mc	1.05	.0351	.0985
2.5 mc	1.08	.0272	.074
3.0 mc	1.1	.0156	.046

APPENDIX II (CONTINUED)

4. System under Condition D.

Frequency	Input (millivolts)	Output (volts)	Relative Amplitude
10 kc	1.3	.45	1.0
100 kc	1.21	.335	0.8
300 kc	1.13	.0945	0.242
500 kc	1.11	.0522	.135
700 kc	1.12	.035	.09
1.0 mc	1.1	.0234	.062
1.5 mc	1.08	.155	.042

APPENDIX II (CONTINUED)

Part C: Phase characteristic data for the over-all system under the four band-width conditions.

1. System under Condition A.

Frequency	Phase Delay (degrees)
22 kc	0
360 kc	90
1130 kc	180
1800 kc	270
2200 kc	360
2520 kc	450
3050 kc	540
3700 kc	630
4250 kc	720
4650 kc	810

APPENDIX II (CONTINUED)

2. System under Condition B.

Frequency	Phase Delay (degrees)
21.2 kc	0
318 kc	90
730 kc	180
1300 kc	270
1820 kc	360
2220 kc	450
2580 kc	540
2820 kc	630

APPENDIX II (CONTINUED)

3. System under Condition C.

Frequency	Phase Delay (degrees)
19.5 kc	0
199 kc	90
495 kc	180
1110 kc	270
1800 kc	360
2130 kc	450
2580 kc	540

4. System under Condition D.

Frequency	Phase Delay (degrees)
14.8 kc	0
100 kc	90
400 kc	180
1230 kc	270

APPENDIX III

THE SENSITIVITY OF THE SCANNING SPOT ALONG THE SCANNING LINE

From the text it is seen that the spot sensitivity is given by the following equation:

$$S(x,y) = K_1 e^{-\pi r^2/b^2}$$

This can be written as

$$S(x,y) = K_1 e^{-\pi x^2/b^2 - \pi y^2/b^2}$$

or

$$S(x,y) = K_1 e^{-\pi x^2/b^2} e^{-\pi y^2/b^2}$$

If the sensitivity of the scanning spot is regarded as the third dimension, its sensitivity along the scanning line at a distance x from the spot center will be proportional to the area of intersection between the scanning spot and a plane perpendicular to the scanning line. Thus the sensitivity is found as follows:

$$S(x) = K_1 e^{-\pi x^2/b^2} \int_{-\infty}^{\infty} e^{-\pi y^2/b^2}\, dy$$

or[1]

$$S(x) = K_1 b \; e^{-\pi x^2/b^2}$$

---

[1]C. D. Hodgman, Handbook of Chemistry and Physics, (Chemical Rubber Publishing Co., Cleveland, 1947), p. 241, equation 352.

or

$$S(x) = K_2 \, e^{-\pi x^2/b^2}$$

APPENDIX IV

RESPONSE OF THE SCANNING SPOT TO AN ABRUPT CHANGE OF BRIGHTNESS ALONG THE SCANNING LINE

A. Derivation of Formula

From the text it is seen that:

$$e(X) = K_3 \int_{-\infty}^{\infty} S'(X)\, B(X + x)\, dx$$

The special case of an abrupt change of brightness at X_1 will be considered. That is,

$$B(X + x) = 0 \quad \text{when } (X + x) \text{ is less than } X_1$$

$$B(X + x) = B_1 \quad \text{when } (X + x) \text{ is greater than } X_1$$

That is,

$$B(X + x) = 0 \quad \text{when } x \text{ is less than } X_1 - X$$

$$B(X + x) = B_1 \quad \text{when } x \text{ is greater than } X_1 - X$$

The quantity $(X_1 - X)$ represents the distance from the spot center to the step of brightness and will be referred to as x_1.

Since

$$\int_{-\infty}^{\infty} f(x)\, dx = \int_{-\infty}^{a} f(x)\, dx + \int_{a}^{\infty} f(x)\, dx,$$

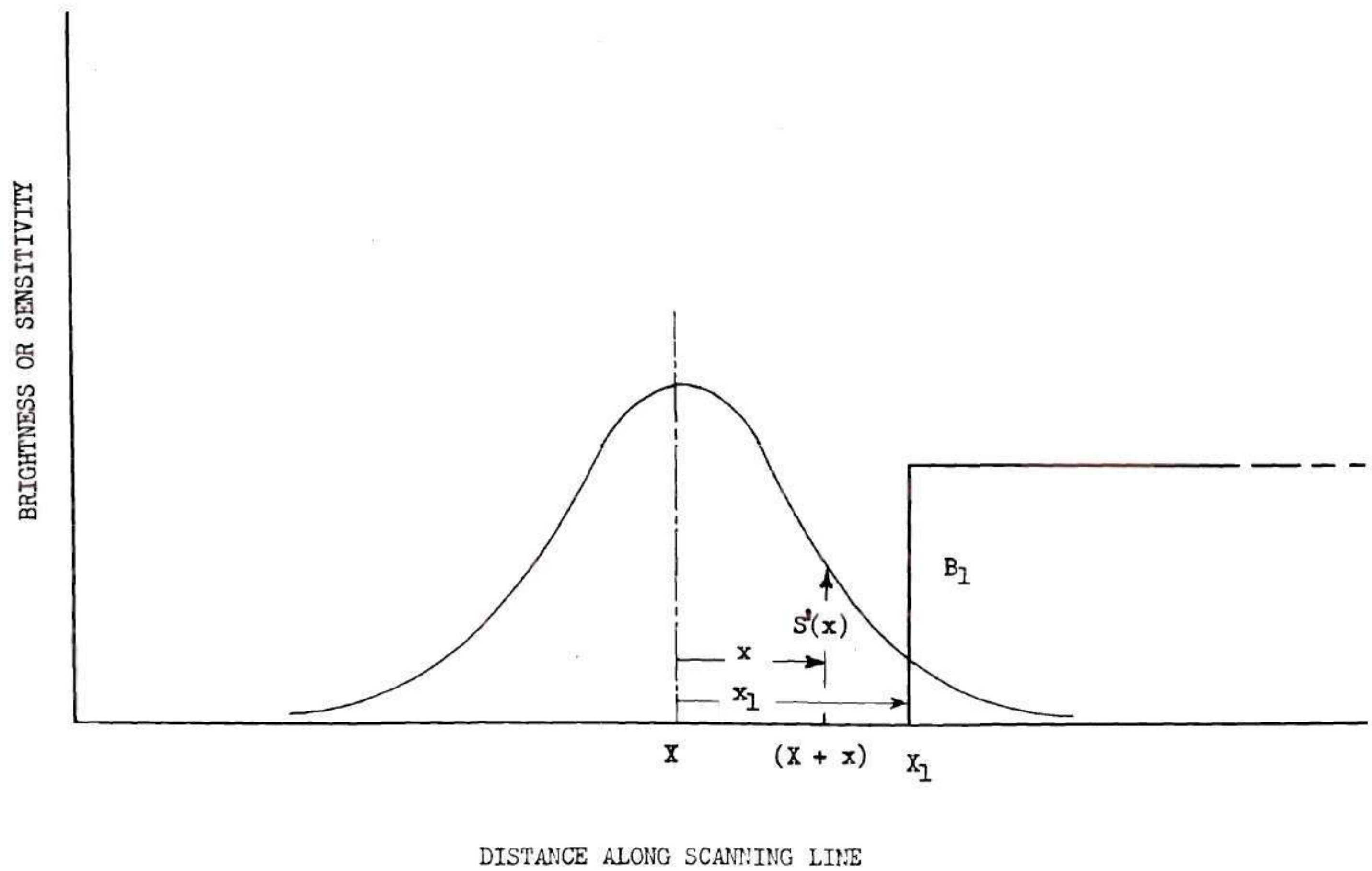


Fig. 1 RESPONSE OF SCANNING SPOT TO STEP OF BRIGHTNESS

then

$$e(X) = e_1(x_1) = K_3 \int_{-\infty}^{x_1} 0 \cdot S'(x)\,dx + K_3 \int_{x_1}^{\infty} B_1\, S'(x)\,dx$$

or

$$e_1(x_1) = K_3 B_1 \int_{x_1}^{\infty} S'(x)\,dx$$

or

$$e(X) = K_3 B_1 \int_{X_1 - X}^{\infty} S'(x)\,dx \qquad (2)$$

B. Evaluation of the Integral.

Since

$$S'(x) = K_2\, e^{\frac{-\pi x^2}{b^2}}$$

then

$$e_1(x_1) = K_4 \int_{x_1}^{\infty} e^{\frac{-\pi x^2}{b^2}}\,dx$$

where $K_4 = K_2 K_3 B_1$

This equation gives the signal from the scanning spot as a function of the distance from the spot center to the step of brightness. However, it is more convenient to express this distance in terms of the spot diameter.

Therefore

$$\text{let} \quad \dot{y} = \frac{x}{b}$$

$$\text{then} \quad dx = b\, d\dot{y}$$

$$\text{when} \quad x = x_1$$

$$\dot{y} = \frac{x_1}{b}$$

Therefore

$$e_2\left(\frac{x_1}{b}\right) = K_4 b \int_{\frac{x_1}{b}}^{\infty} e^{-\pi \dot{y}^2}\, d\dot{y}$$

This form of integral is evaluated in the tables only from 0 to the upper limit. Therefore the integral is expressed in this form:

$$e_2\left(\frac{x_1}{b}\right) = K_4 b \left[\int_0^{\infty} e^{-\pi \dot{y}^2}\, d\dot{y} - \int_0^{\frac{x_1}{b}} e^{-\pi \dot{y}^2}\, d\dot{y}\right]$$

or[1]

$$e_2\left(\frac{x_1}{b}\right) = K_4 b \left[\frac{1}{2} - \int_0^{\frac{x_1}{b}} e^{-\pi \dot{y}^2}\, d\dot{y}\right]$$

The following integral is evaluated in the tables.[2]

$$f(t_1) = \frac{1}{\sqrt{2\pi}} \int_0^{t_1} e^{-\frac{t^2}{2}}\, dt$$

---

[1]Ibid, p. 241, Equation 352.

[2]Ibid, "Areas, Ordinates, and Derivatives of Normal Curve of Error," p. 204.

When t_1 is positive, $f(t_1)$ is positive; when t_1 is negative, $f(t_1)$ is negative.

Therefore,

$$\text{let} \quad \dot{y} = \frac{t}{\sqrt{2\pi}}$$

then

$$e_2\left(\frac{x_1}{b}\right) = K_4 b \left[\frac{1}{2} - \frac{1}{\sqrt{2\pi}} \int_0^{\sqrt{2\pi}\left(\frac{x_1}{b}\right)} e^{-\frac{t^2}{2}} \, dt \right]$$

Values of this function are presented in the following table.

TABLE I

RESPONSE OF THE SCANNING SPOT TO AN ABRUPT CHANGE

OF BRIGHTNESS ALONG THE SCANNING LINE

x_1/b	$e_2(x_1/b)$	x_1b	$e_2(x_1/b)$
+1.44	0.0002	-0.0	0.500
+1.36	0.0003	-0.08	0.579
+1.28	0.0007	-0.16	0.655
+1.2	0.0013	-0.24	0.726
+1.12	0.003	-0.32	0.788
+1.04	0.005	-0.40	0.841
+0.96	0.008	-0.48	0.885
+0.88	0.014	-0.56	0.919
+0.80	0.023	-0.64	0.945
+0.72	0.036	-0.72	0.964
+0.64	0.055	-0.80	0.977
+0.56	0.081	-0.88	0.986
+0.48	0.115	-0.96	0.992
+0.40	0.159	-1.04	0.995
+0.32	0.212	-1.12	0.997
+0.24	0.274	-1.2	0.9987
+0.16	0.345	-1.28	0.9993
+0.08	0.421	-1.36	0.9997
0.0	0.500	-1.44	0.9998

APPENDIX V

AMPLITUDE CHARACTERISTIC OF THE SCANNING SPOT

From the text it is seen that the amplitude characteristic of the scanning spot, or the spot admittance, is given by the following equation:

$$Y(k) = K \int_{-\infty}^{\infty} e^{-\pi x^2/b^2} \cos (2\pi kx/Wn)\, dx$$

This is of the form:

$$Y(k) = 2K \int_{0}^{\infty} e^{-A^2x^2} \cos Bx\, dx$$

This integral is evaluated in the tables, and gives the following results.[1]

$$Y(k) = K\, b\, e^{-\pi k^2 b^2/W^2 n^2}$$

Since

$$f = k N \qquad (N = \text{field frequency})$$

$$(f = \text{video frequency})$$

$$Y'(f) = K\, b\, e^{-\pi b^2 f^2/W^2 n^2 N^2}$$

---

[1] Ibid., p. 242, Equation 361.

TABLE I

AMPLITUDE CHARACTERISTICS OF SCANNING SPOT

Frequency	Relative Amplitude b = 0.01 cm.	Relative Amplitude b = 0.02 cm.
0		1.0
10 kc	1.0	1.0
100 kc	1.0	1.0
500 kc	0.996	0.984
700 kc	0.992	0.968
1 mc	0.984	0.938
1.5 mc	0.965	0.866
2 mc	0.938	0.774
2.5 mc	0.909	0.67
3.0 mc	0.866	0.563
3.5 mc	0.822	0.456
4.0 mc	0.774	0.36
4.5 mc	0.724	0.274
5.0 mc	0.67	0.2
6.0 mc	0.563	0.10
8.0 mc	0.36	0.02
10.0 mc	0.202	0.0008

APPENDIX VI

DESIGN OF BAR CHARTS

The following information was used in the design of the bar charts:

mosaic height = h = 5.52 cm. (measured)

length of subject in test position = a (measured)

length of image of subject on mosaic = a' (measured)

F = optical reduction factor = a/a'

resolution (lines) = R

(width of bar in test position corresponding to R) = d_R

(width of bar image on mosaic corresponding to R) = d'_R

Then it is apparent that:

$$R = h/d'_R$$

and hence:

$$R = hF/d_R$$

Therefore

$$d_R = hf/R$$

This equation gives the width of bars on the test pattern corresponding to a given resolution. However, it was not practical to construct such narrow bars with the desired accuracy. Therefore the bars were constructed P times the desired size and reduced photographically by the factor P. The preceding equation is thus modified:

D_R = (width of bar on constructed chart corresponding to R) = PhF/R

The following table indicates the resolution of the television system corresponding to the number of bars visible over the system.

TABLE I

RESOLUTION CORRESPONDING TO BAR CHART READINGS

Bar Chart 1

Number of Bars Resolved	Corresponding Resolution
1	50
2	55
3	60
4	65
5	70
6	75
7	80
8	85
9	90
10	95

Bar Chart 2

Number of Bars Resolved	Corresponding Resolution
1	100
2	110
3	120
4	130
5	140
6	150
7	160
8	170
9	180
10	190

Bar Chart 3

Number of Bars Resolved	Corresponding Resolution
1	200
2	220
3	240
4	260
5	280
6	300
7	320
8	340
9	360
10	380

APPENDIX VII

RESULTS OF BAR CHART OBSERVATIONS

The results of six selected bar-chart observation tests are shown below. Each entry indicates the number of bars which were resolved under the indicated network condition. The charts were presented in the same order as the column headings are listed. The letter F (Forward) indicates that the bar chart was presented in such a manner that the scanning beam progressed from the narrow bars toward the wide bars, and the letter B (Backward) indicates that the bar chart was inserted so that the scanning beam progressed from the wide bars toward the narrow bars. For example, in Table 1 the entry "5" indicates that under Condition A, when Bar Chart 3 was inserted so that it was scanned from the wide bars toward the narrow ones, 5 bars were resolved by Observer (a).

TABLE 1

Observer (a)

Card:	1B	3F	2F	1F	3B	2B
Net C	10	0	7	10	0	6
Net A	10	6	10	10	5	10
Net B	10	1	9	10	0	10
Net D	10	0	3	10	0	2

TABLE 2

Observer (b)

Card:	1B	3F	2F	1F	3B	2B
Net C	10	0	7	10	0	7
Net A	10	3	10	10	3	10
Net B	10	0	8	10	1	9
Net D	10	0	2	10	0	2

TABLE 3

Observer (c)

Card:	1B	3F	2F	1F	3B	2B
Net C	10	0	9	10	0	6
Net A	10	3	10	10	3	10
Net B	10	1	9	10	0	8
Net D	8	0	3	9	0	3

TABLE 4

Observer (d)

Card:	1B	3F	2F	1F	3B	2B
Net C	10	1	9	10	0	10
Net A	10	3	10	10	3	10
Net B	10	1	10	10	0	10
Net D	10	0	6	10	0	5

TABLE 5

Observer (e)

Card:	1B	3F	2F	1F	3B	2B
Net C	10	1	10	10	0	10
Net A	10	4	10	10	4	10
Net B	10	2	10	10	0	10
Net D	10	0	10	10	0	5

TABLE 6

Observer (e)

Card:	1B	3F	2F	1F	3B	2B
Net C	10	1	8	10	0	10
Net A	10	3	10	10	3	10
Net B	10	2	9	10	0	10
Net D	10	0	7	10	0	4

APPENDIX VIII

DISPLACEMENT MODULATION

During the course of this research the monitor deflection circuit was examined to determine if there was any non-linearity in the scanning voltage due to the introduction of video signal through stray coupling. By viewing the horizontal saw-tooth signal on the oscilloscope, the video signal was seen to be coupled in the horizontal deflection voltage. While investigating this form of distortion, it was observed that when the scope sweep was set at the field frequency, the television image could be observed on the oscilloscope. This phenomenon is explained by the following example.

The transmission of a vertical white bar on a gray background as shown in Figure 1a will be considered. The brightness of the field along a scanning line is shown in Figure 1b. Neglecting aperture distortion, a video signal proportional to the brightness along any scanning line will be generated, as shown in Figure 1c. If a portion of this video signal is added to the normal horizontal deflection voltage in the receiver shown in Figure 1d, the resulting sum wave will be shown by Figure 1e. When this sum wave is applied to the horizontal deflection plates in the receiver, the path of the scanning spot will be that shown in Figure 2a, omitting the retrace lines. From the enlarged section in Figure 2b, it is seen that paths a-b, c-d, and e-f are traversed by the spot at the normal scanning velocity, while the portions b-c and d-e are traversed in zero time, that is, at an infinite velocity.

The paths covered by the spot while moving with normal velocity

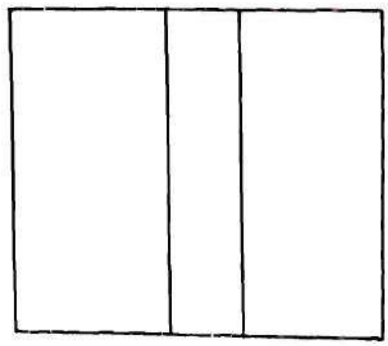


Fig. 1a VERTICAL BAR

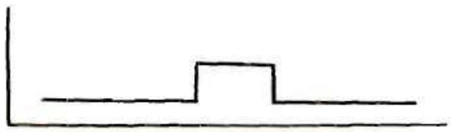


Fig. 1b BRIGHTNESS OF BAR

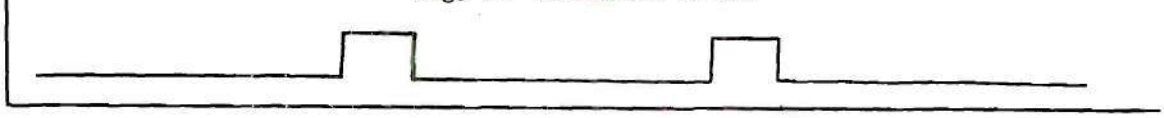


Fig. 1c VIDEO SIGNAL

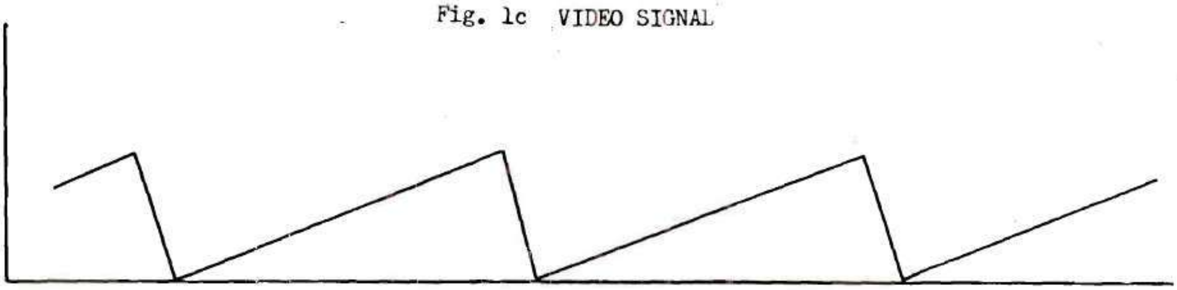


Fig. 1d NORMAL KINESCOPE DEFLECTION VOLTAGE

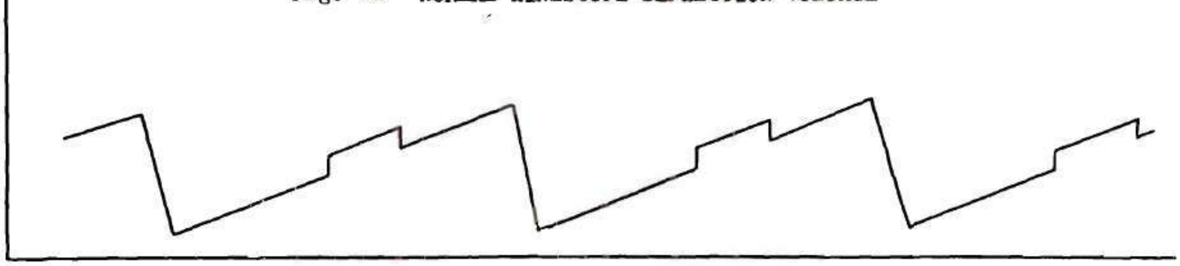


Fig. 1e VIDEO SIGNAL ADDED TO DEFLECTION VOLTAGE

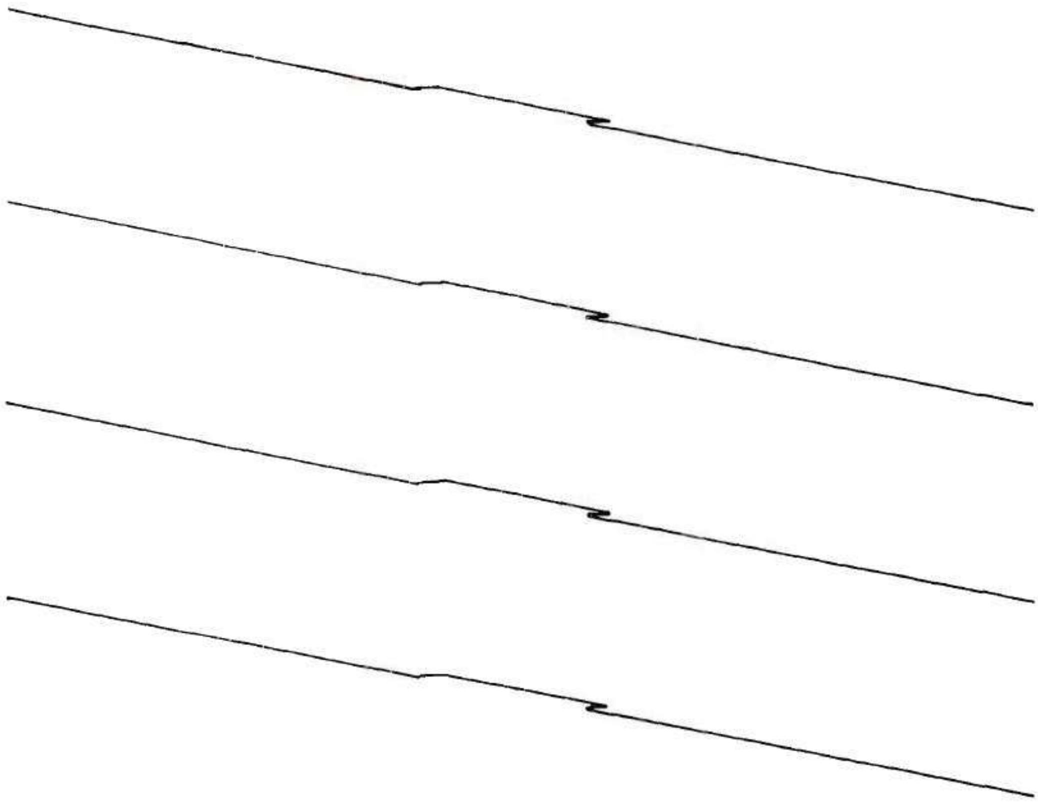


Fig. 2a RESULTING PATH OF SCANNING SPOT

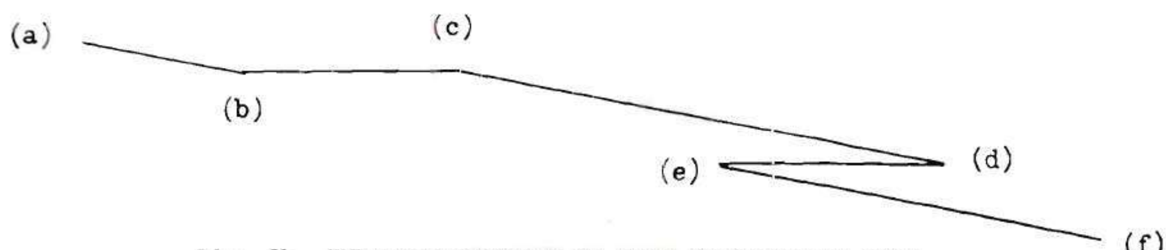


Fig. 2b ENLARGED SECTION OF PATH OF SCANNING SPOT

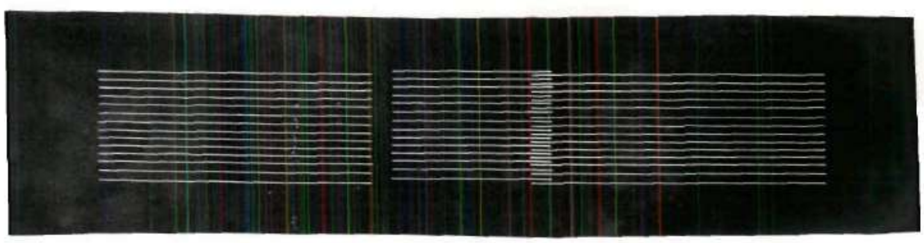


Fig. 2c RESULTING IMAGE ON KINESCOPE

will be of normal brightness, while the paths traversed with an infinite velocity will have zero brightness. If the resulting image is synthesized and the lines of zero brightness are omitted, the effect will be that of a dark edge corresponding to the left side of the bar, and a bright edge corresponding to the right side of the bar, as seen in Figure 2c. Except for the edges, the image of the bar will be of the same brightness as the background.

An example of an image produced by this method is shown in Figure 3.

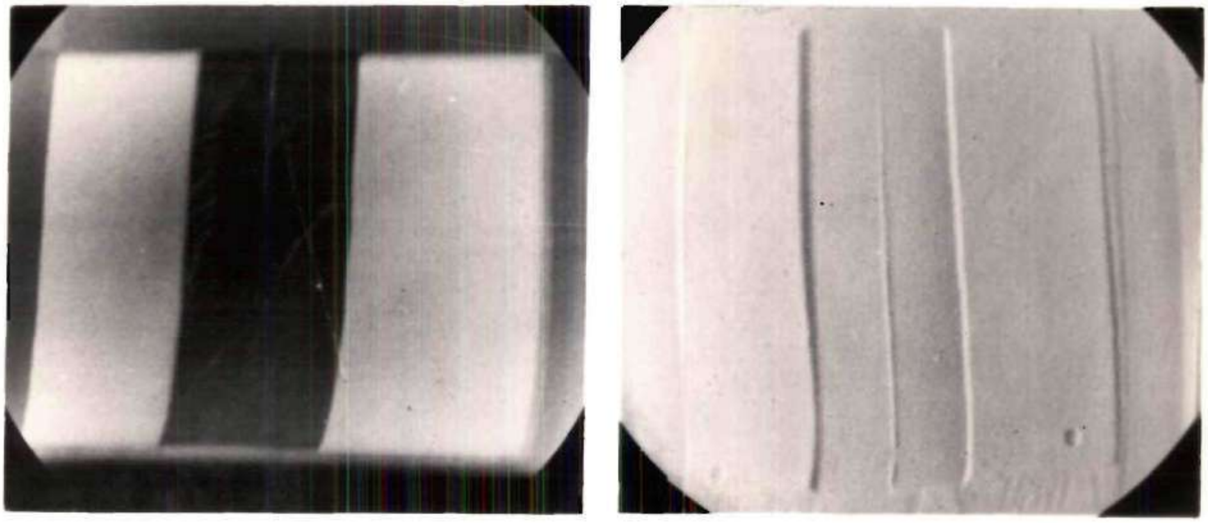
Next it is desirable to see how a general video signal will be reproduced. Consider the video signal shown in Figure 4 and in particular, consider the portion dl with end-points a and b. The reproducing spot at time T_1 will be shifted by an amount proportional to the brightness B_1 at that time; for instance, it will be shifted K_2B_1 units to the left. Then the position of the spot at time T_1 will be $X_1 = K_1T_1 - K_2B_1$ since the abscissa of the spot also increases directly proportional to time. In the same manner, the position of the spot at time T_2 is given by $X_2 = K_1T_2 - K_2B_2$. Then the distance traversed by the spot during the time $dT = T_2 - T_1$ will be:

$$dX = X_2 - X_1 = K_1(T_2 - T_1) - K_2(B_2 - B_1)$$

or

$$dX = K_1dT - K_2dB$$

Therefore, since the brightness is inversely proportional to the spot velocity, the brightness is given by:



BEAM MODULATION (CONDITION A) DISPLACEMENT MODULATION

FIG. 3 WIDE VERTICAL BAR REPRODUCED BY DISPLACEMENT MODULATION IN COMPARISON WITH CONVENTIONAL REPRODUCTION

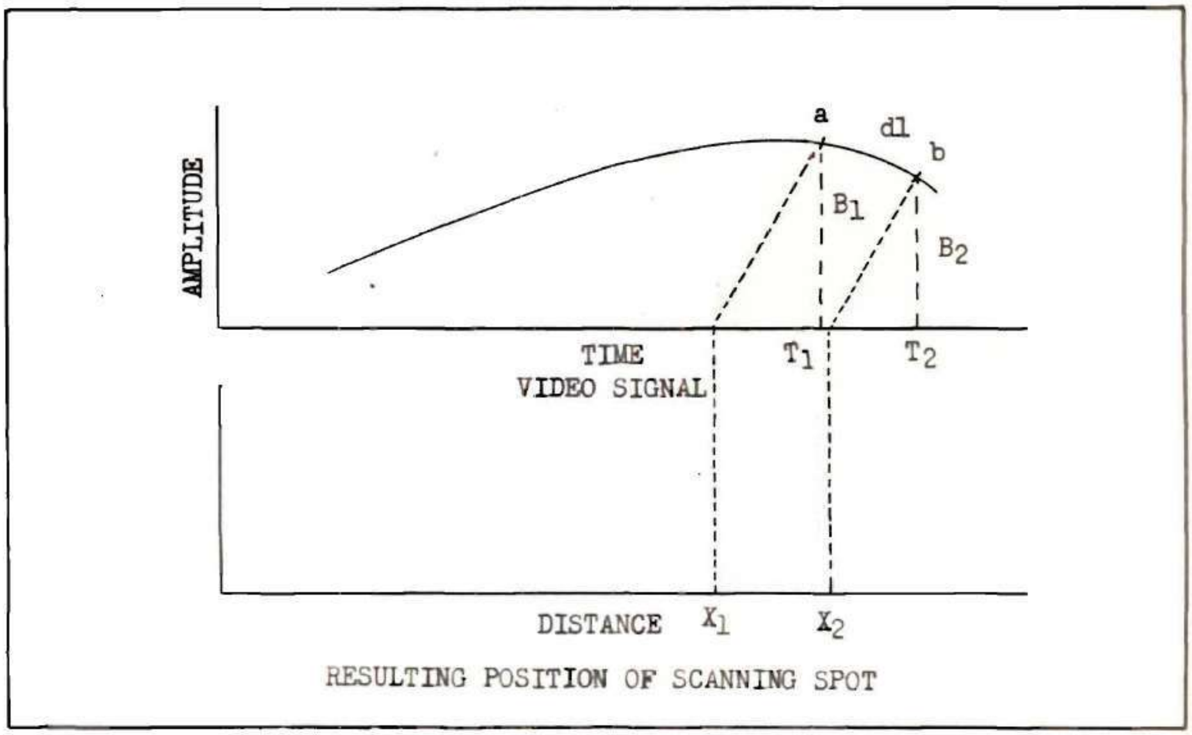


FIG. 4 POSITION OF SCANNING SPOT AT TWO INSTANTS DUE TO INSERTION OF PORTION OF VIDEO SIGNAL INTO DEFLECTION CIRCUIT

$$dB' = K/(\text{velocity}) = K/(\text{distance}/\text{time})$$

$$dB' = K/(dX/dT) = (K\ dT)/(K_1 dT - K_2 dB)$$

Then

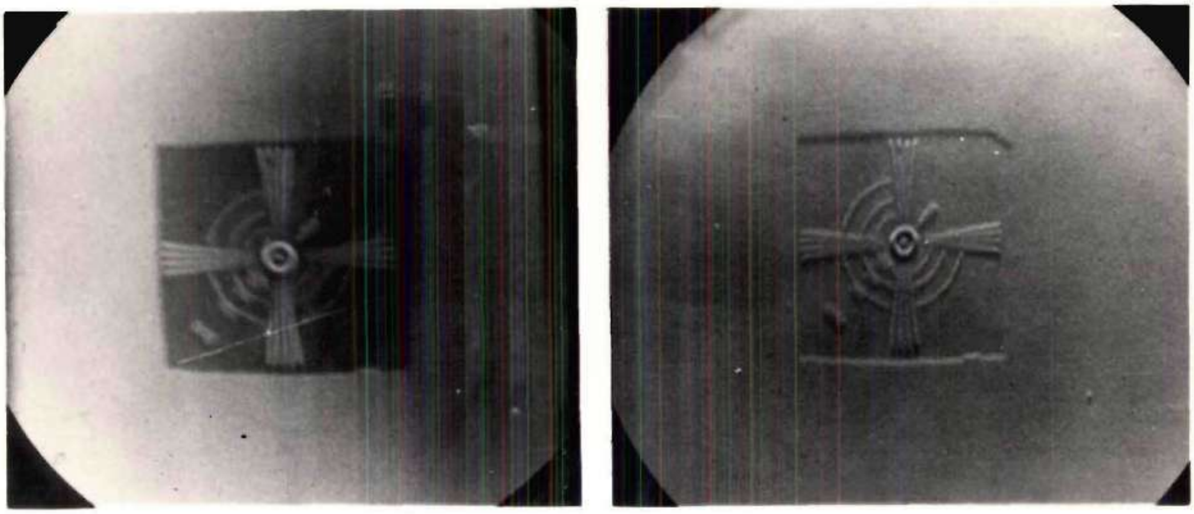
$$dB' = K/(K_1 - K_2 m)$$

where $m = dB/dT$ is the slope of the video signal wave. The above brightness should be written as an absolute value since the brightness is the same whether dX or -dX is traversed in time dT.

It must be noted that this gives the brightness contributed by dl. The portion of the scanned line dX may have other contributions of brightness besides that from dl. In other words, the brightness of dX is not single-valued.

In the preceding discussion the deflected path was assumed to coincide with the normal path of the scanning spot. While this is not true when a portion of the video signal is introduced in the horizontal deflection circuit alone, if the proper amount is also introduced in the vertical circuit, the two paths will coincide. This is not necessary, however, because the eye integrates the two adjacent paths and gives the same apparent brightness as if they did coincide. The only effect of introducing the video signal into the vertical circuit is the possibility of greater saturation of the fluorescing material on the kinescope screen.

Several objects were photographed to demonstrate the information conveyed by this method of reconstitution. These patterns are presented in Figures 5-7 for direct comparison between the two modulation methods.



BEAM MODULATION (CONDITION A) DISPLACEMENT MODULATION

FIG. 5a SMALL TEST PATTERN

BEAM MODULATION (CONDITION A) DISPLACEMENT MODULATION

FIG. 5b SIMILAR LETTERS

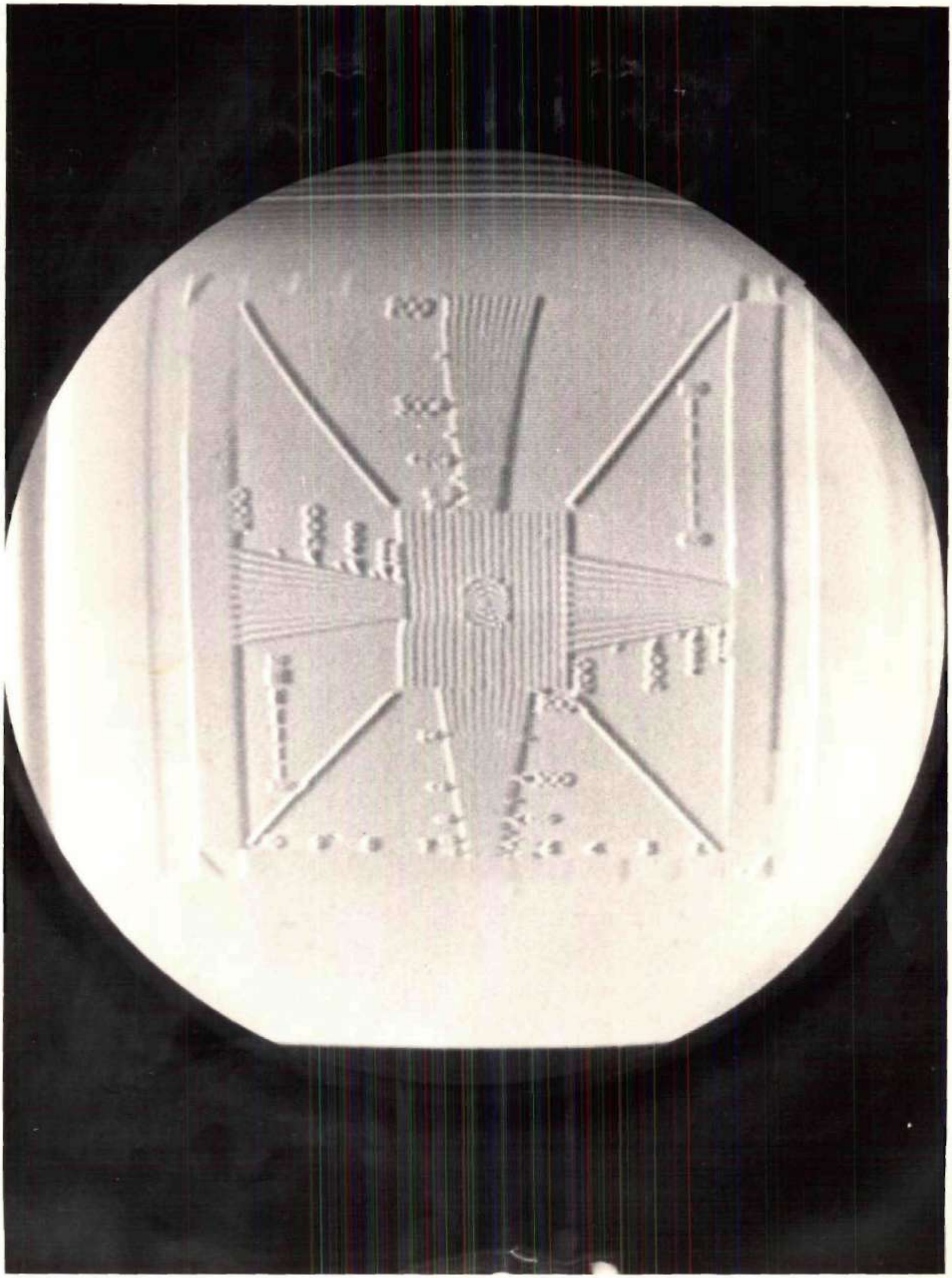


Fig. 6 RMA TEST CHART REPRODUCED BY DISPLACEMENT MODULATION (See Figure 17)

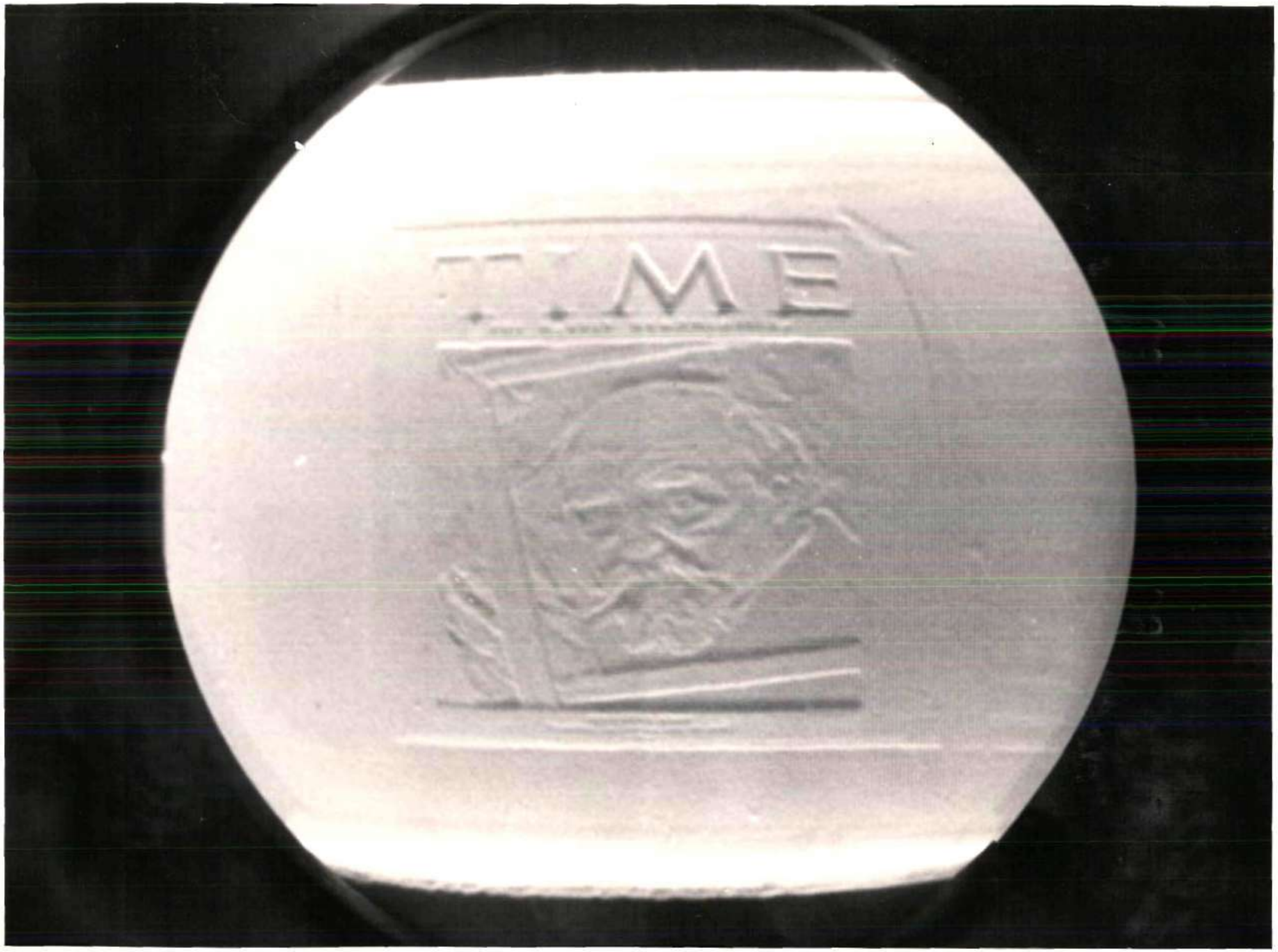


Fig. 7 MAGAZINE COVER REPRODUCED BY DISPLACEMENT MODULATION (See Figure30)

In Figure 5, the images on the left were made over the television system under Condition A and the ones on the right were made on the oscilloscope entirely with displacement modulation. This is not an exact comparison as the images were not presented over the same kinescopes, the electron gun of the oscilloscope being definitely superior to that of the monitor kinescope.

These photographs show the images reproduced on the oscilloscope solely by displacement modulation. The z-axis terminals of the oscilloscope were shorted to insure that there would be no beam modulation. The oscilloscope probe was attached to the horizontal deflection output of the monitor, and the video signal was added to the deflection voltage by stray signal pick-up through the shielded probe cable. The field sweep was supplied by the oscilloscope. It will be noted that these images are reproduced without the use of separate video stages in the oscilloscope (or television receiver), thus permitting the possibility of circuit economy for the special purposes where this form of presentation is applicable.

In summarizing, it may be seen that displacement modulation is a method well adapted to the transmission of information which is conveyed by changes in brightness rather than by the relative brightness of areas. No video stages are needed in a receiver which employs displacement reconstitution. The sending spot and receiving spot are not at corresponding positions on their respective fields as they are in conventional systems.